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WATER-TUBE BOILERS

WATER-TUBE BOILERS

BASED ON A SHORT COURSE OF LECTURES DELIVERED AT UNIVERSITY COLLEGE, LONDON

By LESLIE S. ROBERTSON
M.Inst.C.E., M.I.Mech.E., M.I.N.A.

WITH UPWARDS OF 170 *ILLUSTRATIONS*

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PREFACE

WHEN asked by my friend, Professor Hudson-Beare, to deliver a short course of lectures on Water-Tube Boilers at University College, London, it was not my intention to issue the lectures in book form; but so many of those who attended the lectures desired to have them put in a more permanent shape, that I have acceded to their request. I did so, because I felt that there was no popular book on Water-Tube Boilers to which students and practical engineers could refer. The Standard work by M. Bertin, the able Chief Constructor of the French Navy, which I had the honour of translating into English, contains a mass of valuable information, much of which the author

has kindly allowed me to embody in the present Lectures, but the price of M. Bertin's work places it beyond the reach of many, and it is hoped that the present volume may serve as an introduction to his more exhaustive treatise.

My thanks are due to the Admiralty for some of the information in reference to His Majesty's ships, and to the various firms who have placed valuable information at my disposal. I am indebted to Messrs Babcock & Wilcox, Limited, for the loan of a large number of the blocks illustrating the historical part of the subject, and to M. le Marquis de Chasseloup-Laubat, Mr F. J. Rowan, Mr W. Worby Beaumont, and many others for the use of illustrations.

My thanks are especially due to my assistant, Mr Charles Dresser, for the care he has given to the preparation of these Lectures, and their revision for the press.

The book has retained, more or less, the form of the Lectures, but they have been revised and adapted as far as possible to their present purpose. I should have preferred to recast the book, but

the time at my disposal has been too limited to allow of this. The subject of Water-Tube Boilers has, of late, been so much before the public, and the need of a short practical work of reference appears to be felt in so many quarters, that I decided to issue the book in its present form in the hope that it may prove of some value and interest.

LESLIE S. ROBERTSON.

WESTMINSTER,
September 1901.

The Author has much pleasure in acknowledging his indebtedness to the following, amongst others, for the use of Illustrations :—

INSTITUTION OF CIVIL ENGINEERS . Fig. 62.
Water-Tube Boilers, by Thornycroft, vol. xcix.

INSTITUTION OF NAVAL ARCHITECTS Figs. 39, 124.
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Water-Tube Boilers, by J. A. Normand, vol. xxxvii.

INSTITUTION OF ENGINEERS AND SHIPBUILDERS IN SCOTLAND } Figs. 2, 8, 9, 16, 17, 52, 86, 87.
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M. BERTIN (*Marine Boilers*) . . Figs. 12, 14, 15, 18, 23, 24, 30, 34, 35, 44, 76-78, 92, 93, 107-111, 120, 123, 125-128, 131, 133-135, 141, 142, 146, 151-153, 165, 167-169.

W. WORBY BEAUMONT (*Motor Vehicles and Motors*) . . . . Figs. 80, 81, 82, 83.

The Engineer . . . . Figs. 6, 7, 79, 84.

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WATER-TUBE BOILERS

CHAPTER I

Definition of a Water-Tube or Tubulous Boiler — Classification — Difficulties attending any satisfactory classification of a practical nature—Short Chronological History of Water-Tube Boilers—Early Developments of Water-Tube Boilers in connection with Road Locomotion—Early attempts to use Water-Tube Boilers on board Ship.

1. Scope of Lectures.—In dealing with the question of "Water-tube" or "Tubulous" Boilers, it is utterly impossible in the space of the five lectures allotted to this course to deal with the subject exhaustively or in great detail. It will therefore be beyond the scope of these lectures to deal with the many cognate subjects which should rightly find a place in a course of lectures on boilers, such as the strength of riveted joints, stress in the metal, chemical theory of combustion, analyses of gases, and so forth, but the lectures will rather be devoted to:—

1. An historical description of the better-known types of tubulous boilers, from the early attempts to the present day. No attempt will be made to deal with every description of water-tube boiler invented, nor is it proposed to cite all the early patents taken out for water-tube boilers. Further, it is almost impossible to attempt to keep them in strict chronological order, and this is more particularly the case with recent practice, and therefore, after 1890, no attempt has been made to deal with them in their chronological order.

2. The consideration of the general principles underlying

the construction of steam boilers, but dealing with them only in so far as they immediately concern water-tube boilers.

3. A discussion of the principles underlying the circulation of the water and the hot gases.

4. Short description of the better-known types of water-tube boilers.

5. Boiler mountings and accessories.

6. Weight and space occupied.

7. Advantages and disadvantages of this type of boiler.

2. Definition of a Water-tube Boiler.—It is difficult to give an inclusive, and at the same time an exclusive, definition of what is popularly known as a "water-tube" or "tubulous" boiler. The essential distinguishing feature of the water-tube boiler is that the steam and water are contained within tubes, the fire being external to the tubes: further, the shell of the boiler is composed of a casing which is *not* subject to pressure, as is the case with the shell of the ordinary marine or Scotch boiler. Another distinguishing feature is that the metal forming the tubes in the tubulous boiler is in tension, the pressure being internal, and not in compression, as is the case in the ordinary marine type boiler where the pressure is external to the tubes. In the tubulous boiler the furnace is usually external to the boiler proper, though of course within the casing; in the "marine type" boiler, on the other hand, the furnace is within the boiler shell. Tubulous boilers are generally composed of small elements of cylindrical form, and therefore lighter and better able to withstand high pressures. In contradistinction, the marine boiler has a large shell completely enveloping the fire tubes, combustion chambers, and furnaces, and this shell has to be made sufficiently strong to stand the pressure. As the diameter is very great compared to the smaller elements of the tubulous boiler,

reaching sometimes to 17 or 18 feet in diameter, the thickness of the shell has to be considerable, and therefore the weight excessive: in tubulous boilers the elements are usually of small diameter, and the thickness and weight are consequently greatly reduced.

3. Classification.—The classification of tubulous boilers is after all merely a matter of convenience. Its value is more academic than practical, and it is well-nigh impossible to find any classification which will be satisfactory, and which will include all the boilers of a given class, and at the same time exclude all others not belonging to that class. Different methods of classification have been adopted, such as classifying the boilers according to their construction, or according to the circulation of the water and steam. This latter method is the one adopted by M. Bertin, the Chief Constructor of the French Navy, in his work on Marine Boilers,* but, for simplicity's sake, we propose to deal with them under the two heads of "large-tube" and "small-tube" boilers, dealing with "large-tube" boilers in Chapter III., and with the "small-tube" in Chapter IV.

BLAKEY BOILER.

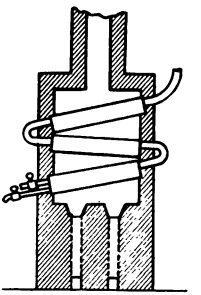


FIG. 1.

4. Brief History of Water-tube Boilers.—It is difficult to decide upon the exact date to be attributed to the introduction of a boiler. In some cases, the date when the patent was taken out has been used; in others, the date given is that of the introduction of the boiler on a practical scale. Perhaps the earliest form of water-tube boiler is that of John Blakey, which was designed in 1774 (Fig. 1). It consisted of three water-pipes, alternately inclined, resembling a Z, and con-

* "Marine Boilers," L. E. Bertin. Translated and edited by Leslie S. Robertson. John Murray, London, 1898.

nected at the ends by bent tubes, so that the steam formed in the lower limb had to find its way through the water contained in the upper tubes of the boiler in order to supply the engine. Passing over Voight and Fitch's pipe boiler, which was put into their steamboat on the Delaware River in America in 1787, Rumsey's boiler, patented in 1788, Pitts' and Strode's boiler, patented in 1792, Dale's in 1793, Barlow and Fulton's boiler, which was fitted to a boat on the Seine in 1793, and Willcox's boiler, patented in 1801, we come to Woolf's sectional boiler, which was patented about 1803 (Fig. 2).

In this boiler a number of cast-iron water-pipes are placed horizontally in a row, and connected by branch pipes to a horizontal tube of large diameter, placed above them at right angles. The water level was half way up the receiver, the upper space being steam space. The pipes were laid transversely to the furnace, and the furnace gases passed alternately over and under them.

WOOLF BOILER.

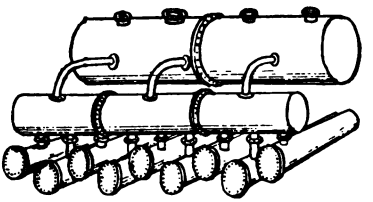


FIG. 2.

STEVENS BOILER.

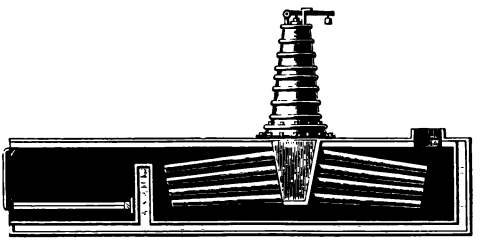


FIG. 3.

Stevens in America employed a form of water-tube boiler (Fig. 3), which he fitted to a screw-boat in 1804.

This boiler contained 100 tubes of 2″ diameter and 18″ long, plugged at one end, and connected at the other to a central water leg, the furnace gases passing around and among the radiating tubes.

Trevithick patented a boiler in 1815, formed of small tubes closed at one end and opening into a common chamber.

In 1819 Seaward patented a boiler in which the tubes,

EVE BOILER.

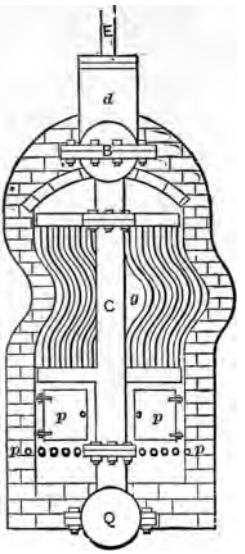


FIG. 4.

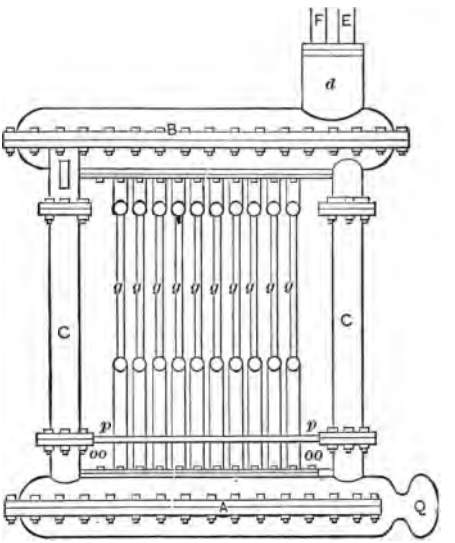


FIG. 5.

which were nearly horizontal, were connected in series so as to form a zigzag course for the steam bubbles to follow. Griffith in 1821 (see Fig. 79) patented a boiler with horizontal water-tubes, the ends of which were inserted into two down pipes; the furnace gases passing over the horizontal tubes.

Tubulous boilers were patented in 1821 by Congreve, in 1822 by Clark, 1824 by Moore, Paul, and M'Curdy, and in 1825 by Eve (Figs. 4 and 5), Teissier, and Gurney. The boilers of Congreve and M'Curdy were of what is sometimes

called the "flash" type, in which there is no reserve of water, the water being instantly converted into steam on passing into the boiler.

Most of the early attempts at "water-tube boiler" construction were in connection with road locomotion. Between the years 1821 and 1835 several boilers of various designs were introduced for road locomotion, the main object in view being to obtain a powerful boiler with a minimum of weight. Between the years referred to, a very considerable advance was made in water-tube boiler construction.

In 1825 Goldsworthy Gurney brought out a tubulous boiler for driving his road carriage. In its later form (Figs. 6 and 7) this boiler consisted of a small bottom cylindrical reservoir, into which were screwed a number of welded iron pipes, which were brought out from this reservoir to a distance of about $4\frac{1}{2}$ feet, and acted as the grate; they were then connected by bends to short vertical pipes, the upper ends of which were jointed to nearly horizontal tubes connected to an upper reservoir parallel to the lower reservoir, to which it was joined by vertical water legs. The furnace was placed between the top and bottom row of tubes. A top steam and water drum was fitted over the upper water-drum. In 1827 one of Gurney's boilers had been running every day for two years without requiring repairs of any importance.

In 1826 boilers were patented by Pearson, Witty, and Gillman, and by Pearson, and Hancock in 1827. Hancock's boiler of 1827 had flat leaves, or cells, stayed with partly counter-sunk rivets, but these gave trouble by leakage. This boiler, in common with those of many other inventors, was intended for propelling steam road carriages. Patents were taken out in 1826 by Hall, in 1829 by Poole, and in 1830 by Summers and Ogle (see Figs. 82, 83), and Rawe and Boase.

GURNEY BOILER.

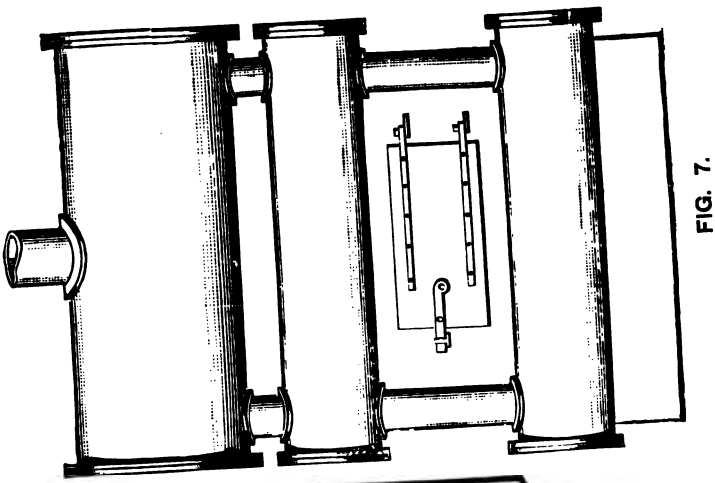


FIG. 7.

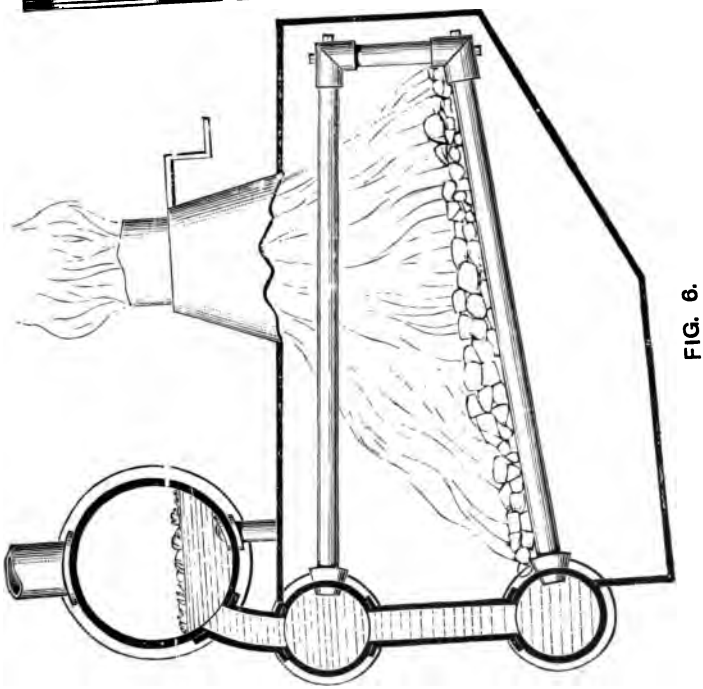


FIG. 6.

In 1831 Jacob Perkins patented a boiler in which the water-tubes, closed at one end, hung vertically downwards into the furnace. These tubes were double (Fig. 8), there being an inner concentric tube open at both ends, which extended nearly to the bottom of the outer tube, but leaving sufficient room for water to circulate between the two tubes. This type is at present generally known as a "Field" tube, a form of it having been subsequently employed in the Field boiler.

PERKINS TUBES.

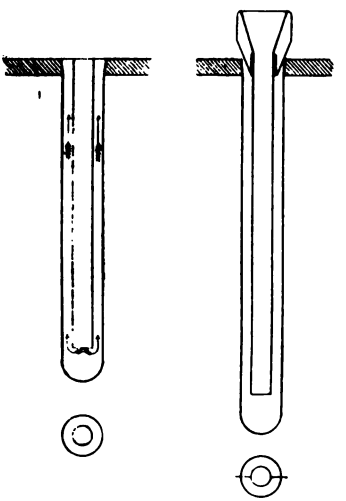


FIG. 8.

Besides Perkins' boiler, one was also patented by Brunton in 1831. This was followed in 1832 by Dance, who brought out a modification of Gurney's boiler. Church (see Fig. 85) and Trevithick also brought out boilers in this year. In 1833 Dance and Field (see Fig. 80), and also Maceroni and Squire (see Fig. 84) invented boilers. The boiler of the latter inventors had a working pressure of 150 lbs. per square inch, a pressure up to that time unheard of. Hancock in this year patented the boiler shown in Fig. 81, which was very successful.

Water-tube boilers were patented by M'Dowall in 1834, by Collier, and Beale in 1836, and in this year Schafhautl brought out what may be termed an "injection" or "flash" boiler, on the same principle as the well-known Serpollet boiler, which has been so largely used for steam motor vehicles in France. Other forms of injection boilers, embodying the same principle, had been previously constructed by Payne, in 1736,

Pitts and Strode in 1792, Dale in 1793, Willcox in 1801, Congreve in 1821, M'Curdy in 1824, and Howard in 1832.

In 1837 Anderson, and Gillman both patented water-tube boilers, followed by Morgan, and James in 1838, by Prosser in 1839, Craddock, and Hill in 1840, and Alban in 1843 (Fig. 9).

Dr Alban published the first description of his boiler in 1843. His boiler consisted of a group of horizontal water-pipes communicating with a vertical water-space. This water-space was connected with two reservoirs above, from which the steam was taken. The water-level was

ALBAN BOILER.

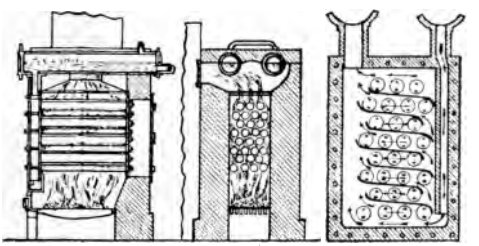


FIG. 9.

half-way up these top reservoirs, the upper halves being filled with steam. The water-pipes, 28 in number, were of copper, 4″ in diameter, about $\frac{1}{10}$ inch thick, and from $4\frac{1}{4}$ to $6\frac{1}{4}$ feet in length, according to requirements. The tubes were closed at the back ends by a screw cover, and screwed into the back plate of the front water-space. Two openings through the plate into each pipe were made; one below the centre of the pipe for the inflow of water, one above for the escape of steam into the chamber. The pipes were slightly inclined upward towards the water chamber to facilitate the escape of steam. The pipes were arranged in eight rows, zigzag, so as to meet and divide the upward

current of the gases, and were spaced $1\frac{1}{2}''$ apart. The steam rose at one side of the chamber into the left-hand reservoir, while the water descended from the right-hand reservoir into the chamber. The coal consumption of a 10 H.P. boiler was 7 to 10 lbs. of coal per square foot of grate per hour.

Water-tube boilers were patented by Craddock in 1844 and 1846, in 1849 by Clarke and Motley, in 1850 by Green, and in 1855 by Isoard, and by Green.

In 1856 Stephen Wilcox patented a boiler (Figs. 10 and 11) with inclined tubes connecting water-spaces front and back, and with an overhead steam and water drum.

WILCOX BOILER.

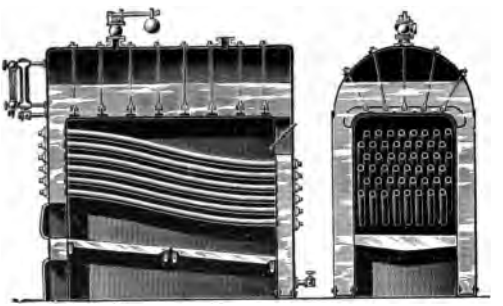


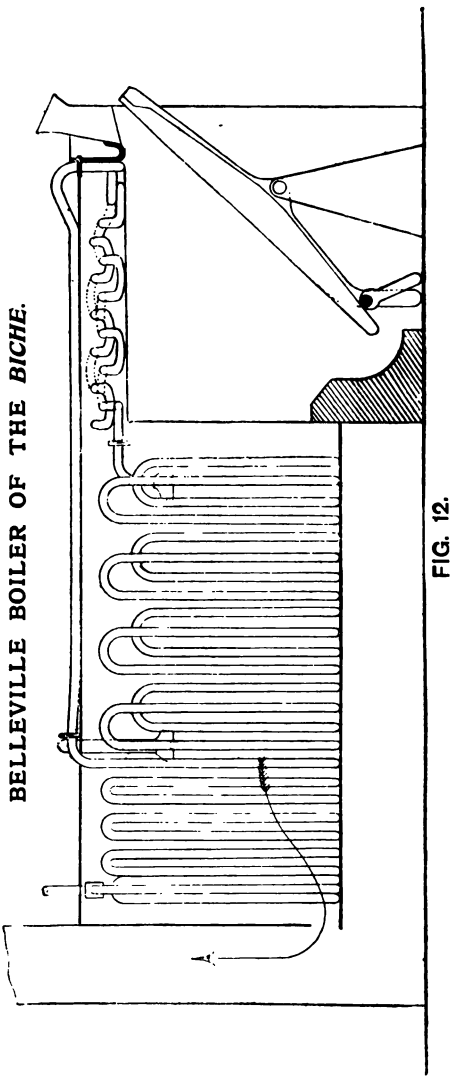
FIG. 10. FIG. 11.

The tubes were bent to a slightly reversed curve, extending over nearly the whole length of the tube, but were inaccessible for cleaning, a fault which is common to most of the early forms of water-tube boilers.

In 1856 the first Belleville boiler was fitted on board the *Biche* (Fig. 12). In this boiler the tubes were vertical and the water circulated in the opposite direction to the current of hot gases, and a feed-heater or economiser was fitted. This boiler was not however a success.*

* "Marine Boilers," L. E. Bertin. Translated and edited by Leslie S. Robertson. John Murray, London, 1898.

Joly in 1857 invented a boiler (Fig. 13) in which vertical tubes with closed ends were suspended over the furnace. They were provided with internal concentric down-pipes, extending nearly to the bottom of the closed tubes, similar to the Field tube. In this year, Messrs Scott & Co., of Greenock, built the *Thetis*, for which a tubulous boiler, working at 120 lbs. pressure, was designed and constructed by Mr J. M. Rowan.



BELLEVILLE BOILER OF THE *BICHE*.

FIG. 12.

The "Sochet" boiler (Figs. 14 and 15) appears to have been the first "small-tube" tubulous boiler of the du Temple or Thornycroft type used in France, but the boiler not being a success, its use was discontinued about 1859. M. Sochet called it a "rapid circulation" boiler, and laid great stress on this point.

In 1859 Messrs Rowan and Horton produced a sectional

JOLY BOILER.

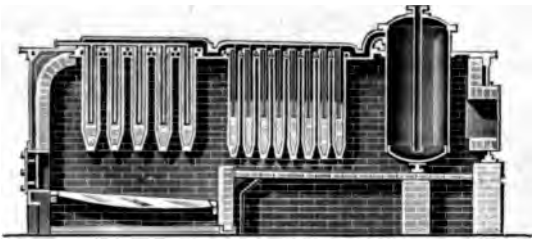


FIG. 13.

SOCHET BOILER.

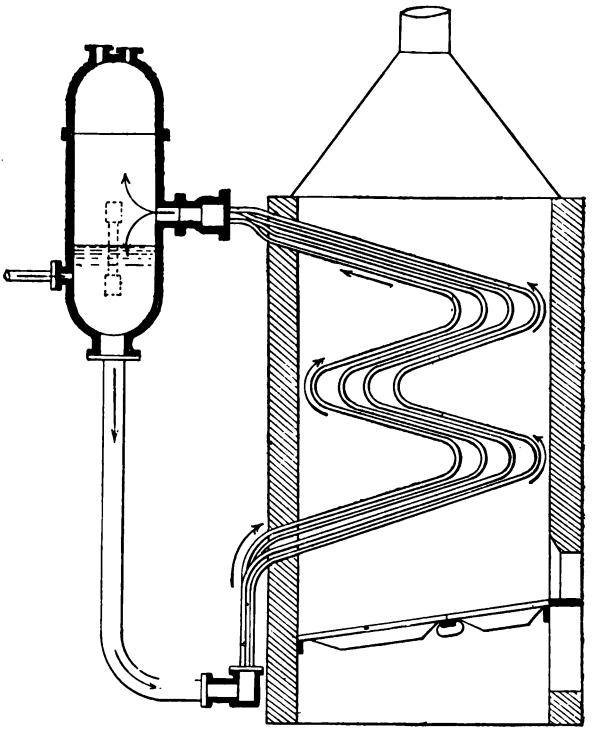


FIG. 14.

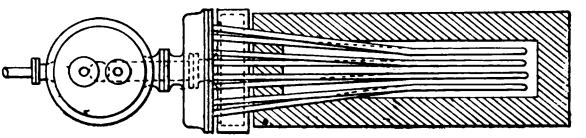


FIG. 15.

boiler, which was fitted on the *Athanasian* by J. R. Napier for the Glasgow and Bordeaux trade, and Williamson and Loftus Perkins patented a water-tube boiler, which in its later form is shown in Fig. 16. In 1860 and 1862 several boilers by Rowan and Horton, similar to the *Athanasian's* boiler, were fitted for home and foreign trade.

In 1860 Barrans brought out a tubulous boiler, and about this time Lamb and Summer's water-tube boiler appears to

L. PERKINS BOILER.

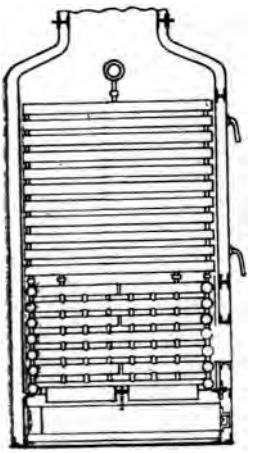


FIG. 16.

ROWAN BOILER, 1861.

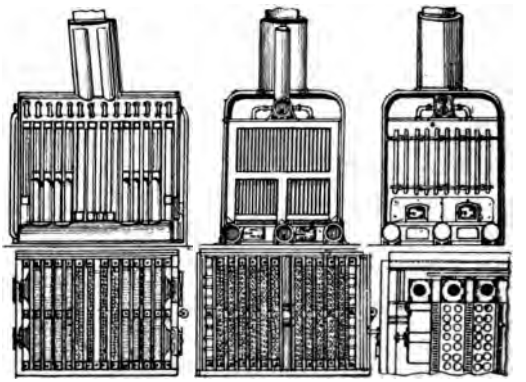


FIG. 17.

have been fitted on board a ship. In the following year water-tube boilers were patented by Williams and by J. M. Rowan (Fig. 17).

In this year (1861) Belleville fitted a new type of boiler (Fig. 18) to the *Argus* and *Sainte Barbe*. The coils in this case were horizontal and continuous, and the furnace gases came first into contact with the tubes full of water, and then ascended vertically among the remaining coils, the steam being taken off from the upper part of the boiler.

In 1861 Mr Howden of Glasgow replaced Messrs Rowan and Horton's boiler on the *Athanasian* by a boiler consisting of a series of horizontal drums in tiers, and joined together by short connecting pipes.

In 1862 Merryweather brought out a boiler (Fig. 19) with drop tubes hanging vertically from the crown of the furnace.

BELLEVILLE BOILER, 1861.

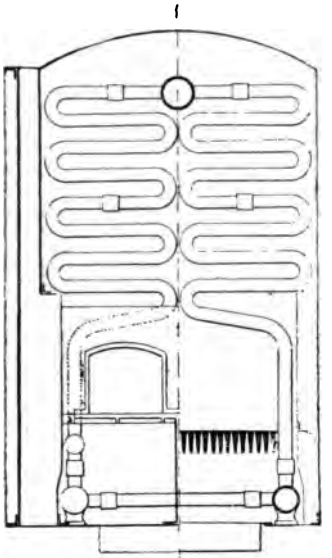


FIG. 18.

MERRYWEATHER BOILER.

FIG. 19.

In 1865 Rowan took out his British patent for a boiler made up of a series of units placed side by side, each unit consisting of an upper and lower horizontal drum, connected by a series of "bent-ended" heating tubes, and, at the front end, outside the setting, with down-take pipes of large diameter (Figs. 20 and 21).

In 1866 Howard of Bedford patented a sectional boiler with vertical tubes, and, in the same year, Field brought out a cylindrical boiler, slightly inclined from the horizontal,

with drop tubes fitted to the under sides of the cylinder (Fig. 22). Belleville, in this year, fitted to the French transport, *Vienne*, and several gun-boats, a boiler very similar to

ROWAN BOILER, 1865.

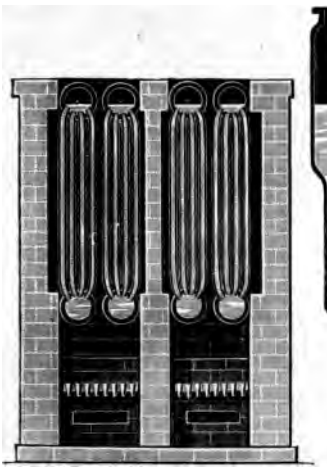


FIG. 20.

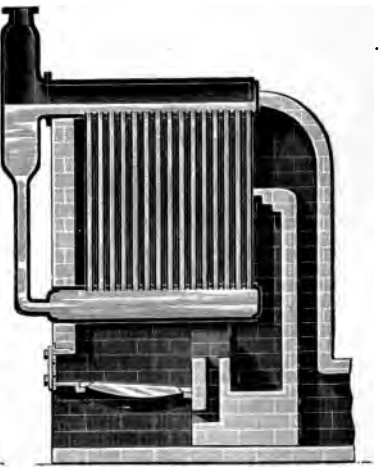


FIG. 21.

his *Argus* type of 1861. The steam was taken from the top of the boiler (Figs. 23 and 24) by a transverse tube or collector, which was surmounted by a tube, called a

FIELD BOILER, 1866.

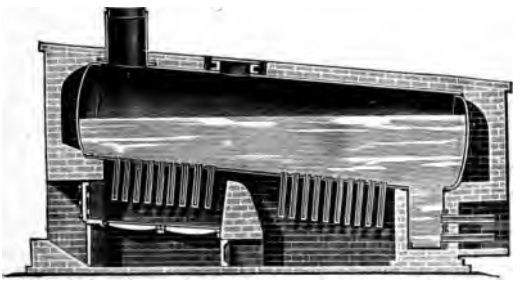


FIG. 22.

"separator," communicating with the collector by small orifices. The tubes were arranged " in series," the ends of the

BELLEVILLE BOILER, 1866.

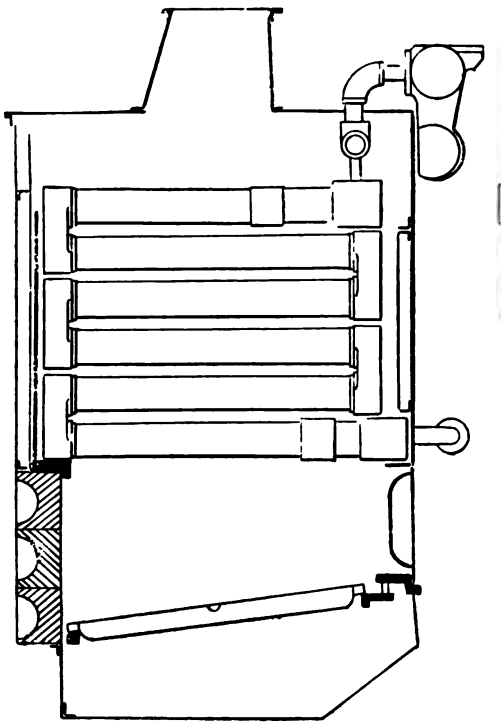


FIG. 23.

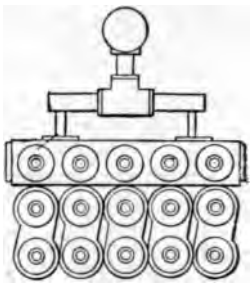


FIG. 24.

tubes being joined by cast-iron junction boxes, so as to force the steam to traverse each tube successively.

FIELD BOILER, 1867.

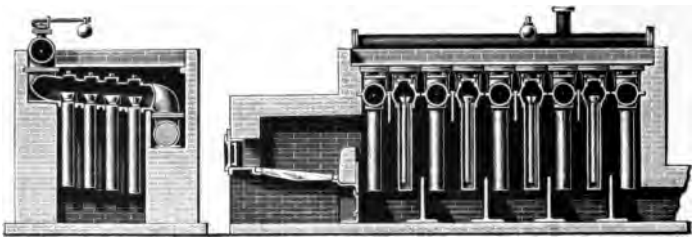


FIG. 25. FIG. 26.

In 1867 Field (Figs. 25 and 26) commenced to use the

internal concentric circulating tube which bears his name, but which had been previously used by Perkins and others. In

BABCOCK AND WILCOX BOILER, 1867.

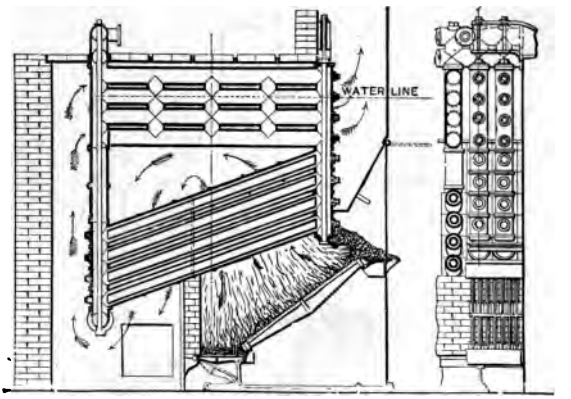


FIG. 27.

this year Babcock and Wilcox patented their first boiler (Fig. 27).

In 1868 Babcock and Wilcox built a boiler (Figs.

BABCOCK AND WILCOX BOILER, 1868.

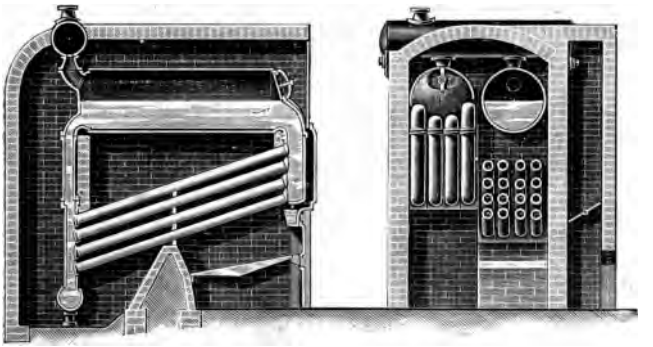


FIG. 28. FIG. 29.

28, 29) with straight, vertical headers. The tubes were brightened, laid in the mould, and the headers cast on. This boiler, to use their own words, "died very young."

About this time Joessel in France invented a steam boiler having fire-tubes inside the water-tubes (Fig. 30).

JOESSEL BOILER.

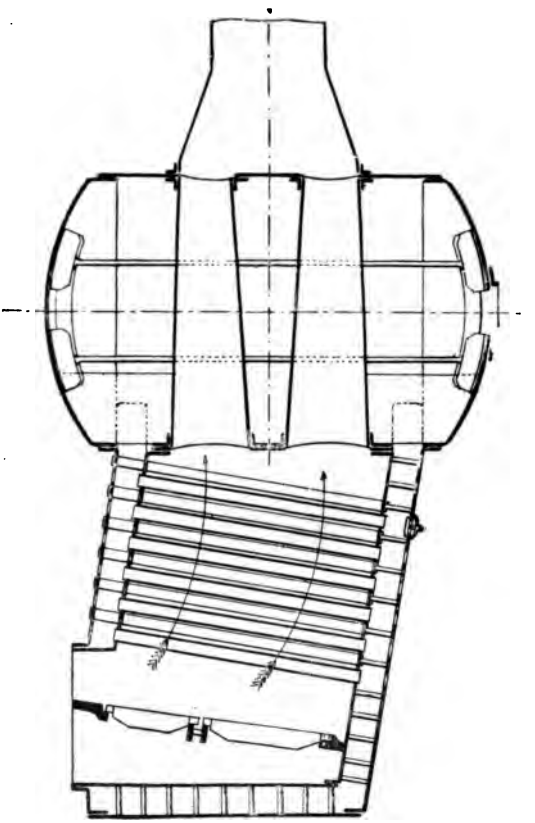


FIG. 30.

In 1869 Rowan and Horton obtained a patent for a water-tube boiler, which was subsequently fitted on the s.s. *Propontis*, and is shown on page 51. In the same year Root brought out a tubulous boiler (Fig. 31), which consisted of a number of wrought-iron tubes, inclined at an angle of 20° from the horizontal, and connected together in pairs back and front, in such a manner that the feed-water entering

the boiler at the rear passed through each tube in succession. The steam was taken off from the top tube by short lengths

ROOT BOILER.

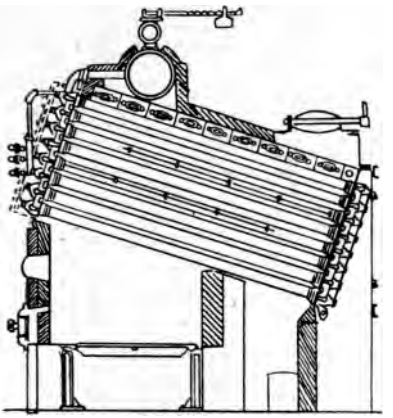


FIG. 31.

FLETCHER BOILER.

FIG. 32.

of pipe, which connected it to the steam drum. Fletcher used a vertical fire-box boiler (Fig. 32), with horizontal cone-

BABBITT BOILER.

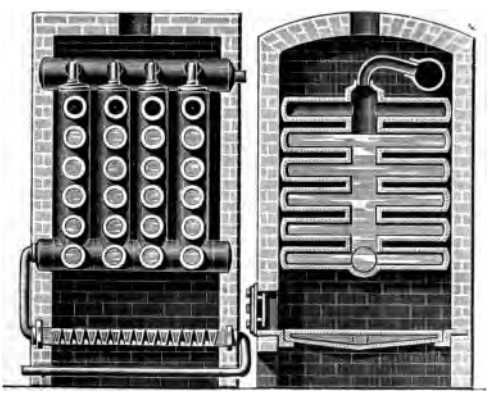
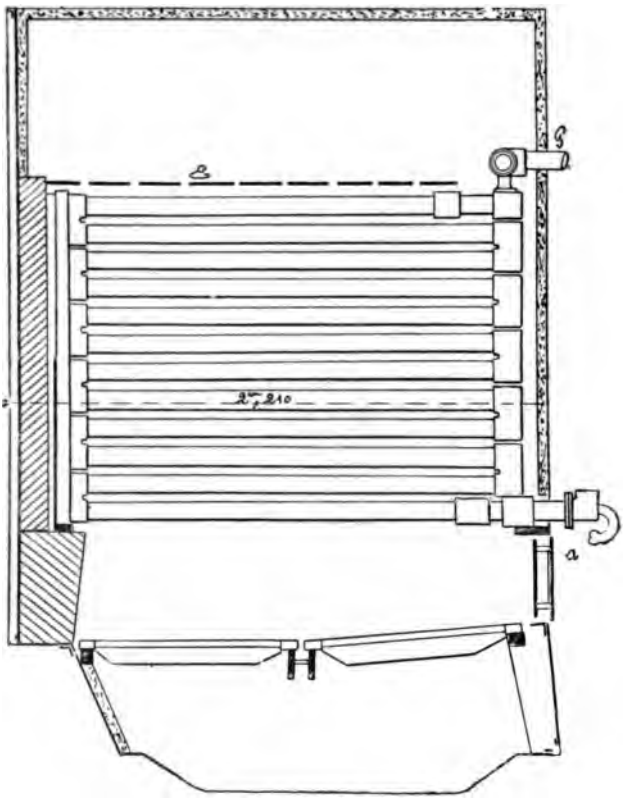


FIG. 33.

shaped water-tubes, radiating from the water-space at the side of the fire-box, towards the centre. Babbitt in New York

BELLEVILLE BOILER OF *HIRONDELLE*, 1869.



P. Steam outlet. **FIG. 34.** *a*. Feed inlet.

SEPARATOR.

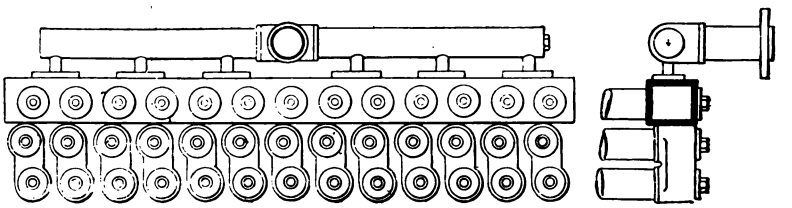


FIG. 35.

made a boiler (Fig. 33) with vertical cast-iron tubes, connected together top and bottom. Each vertical tube had horizontal cast-iron tubes projecting from it on either side. The Belleville boiler of 1866, improved by the addition of a feed-regulator and a vertical separator attached to the steam-pipe, was fitted in 1869 to a fast yacht, the *Hirondelle* (Figs. 34, 35).

HOWARD BOILER.

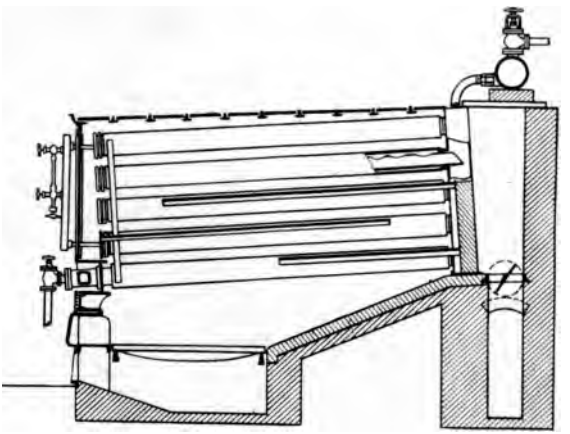


FIG. 36.

In 1869 J. Howard of Bedford patented another water-tube boiler, afterwards known as the "Barrow" boiler. Tubes of large diameter were employed, and were slightly inclined from the horizontal upwards, towards the back of the boiler. Fig. 36 shows one form of this boiler, in which the inclined heating tubes were closed at the front end, the rear end being connected at right angles to a header, from which the steam was taken to a steam-drum, placed transversely to the tubes. An internal concentric circulating tube was fitted inside all the tubes below and up to the water-level, which was in the tubes. The tubes above the water-

level were fitted with horizontal partitions, which extended nearly to the end of the tubes, causing the steam to pass backward and forward along the upper tubes, on its way to the steam-drum, and so become slightly superheated. Two other forms of boiler are shown in the same patent, in which the tubes are connected to headers back and front. Internal circulating tubes were fitted in one of these designs, and were connected at their back end to an internal central

MILLER BOILER.

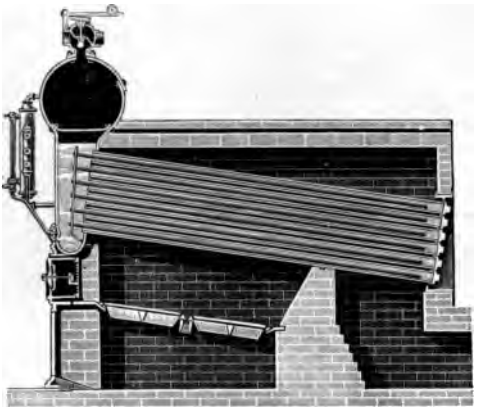


FIG. 37.

chamber in the header, thus separating the steam from the solid water, similarly to the method employed in the Niclausse and Dürr boilers. The other form of boiler was not fitted with any internal tubes.

In 1870 Messrs Barret and Lagrafel patented a boiler, which, in its present improved form, is known as the d'Allest boiler (see Figs. 107, 108). In this year J. A. Miller brought out a tubulous boiler (Fig. 37), with cast headers, to which were fixed closed-ended tubes, with an inner circulating tube. These stood at an angle of 13° with the horizontal.

Maynard also introduced a boiler (Fig. 38) with a horizontal steam and water cylinder above a bank of tubes slightly

MAYNARD BOILER.

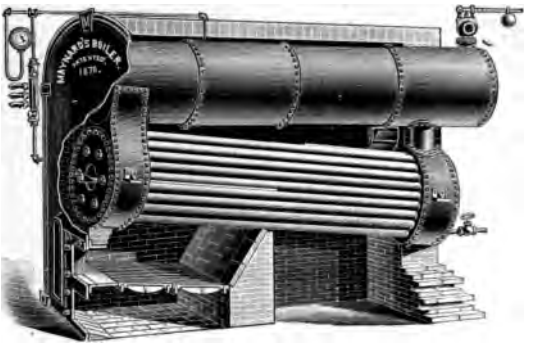


FIG. 38.

inclined from the horizontal, and communicating with them at each end.

Watt patented in 1871 a boiler (Fig. 39) having tubes slightly inclined from the horizontal, and connected at each end to strongly stayed rectangular headers. There was a steam-drum connected to the headers, and the tubes were staggered in the headers.

WATT BOILER.

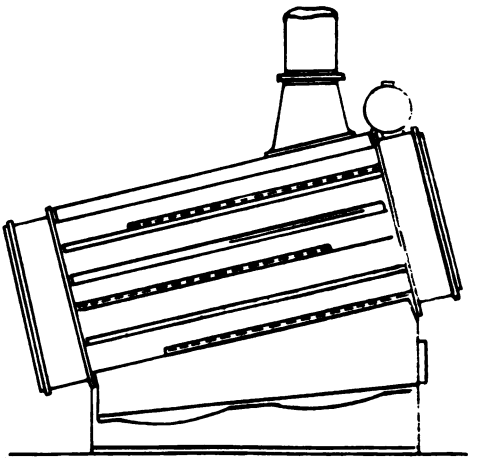


FIG. 39.

In the same year Allen in America brought out a tubulous boiler (Fig. 40) with cast-iron drop tubes screwed into a horizontal tube running along the top, and inclined to the vertical at an angle

of 30'. This boiler was a variation of Joly's of 1857 and Field's of 1866, but did not get beyond the experimental stage. A tubulous boiler was also brought out by Phleger in

ALLEN BOILER.

FIG. 40.

America, in which inclined U tubes were used as fire-bars, as in Gurney's 1825 boiler, but with additional water-tubes above

PHLEGER BOILER.

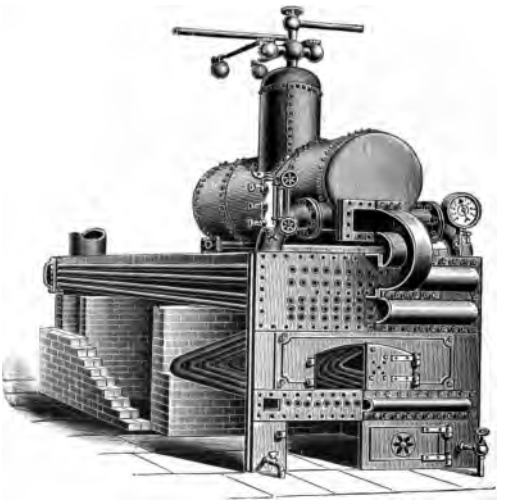


FIG. 41.

WIEGAND BOILER.

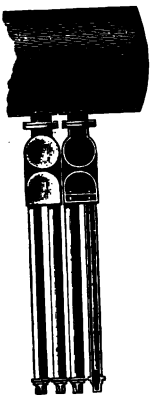


FIG. 42.

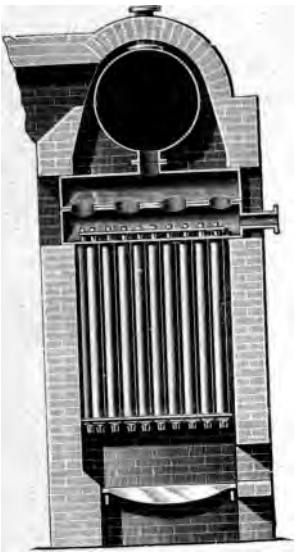


FIG. 43.

them. A large steam and water drum was also provided (Fig. 41).

Wiegand's boiler of 1872 (Figs. 42 and 43) had groups of vertical tubes, provided with inside circulating tubes, connected to an overhead steam and water reservoir.

In this year a new design of Belleville boiler (Fig. 44) was

BELLEVILLE BOILER.

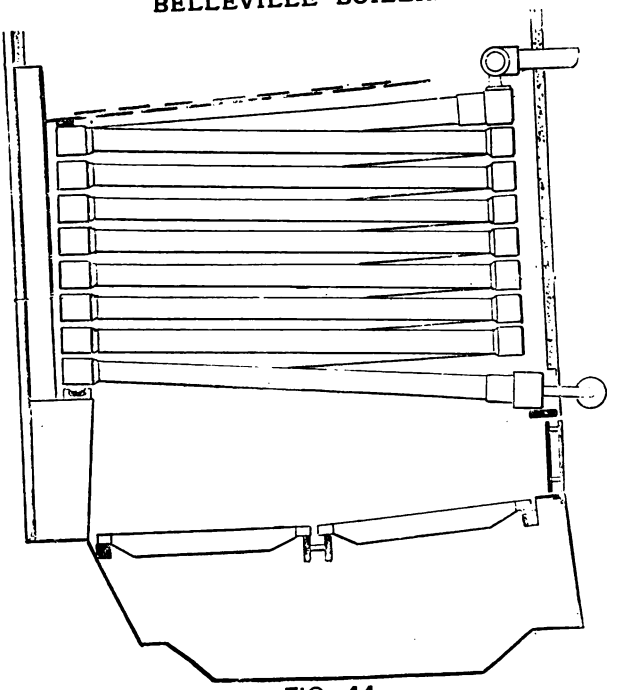


FIG. 44.

brought out and fitted to the *Hirondelle*, as the previous boilers had been unsatisfactory. The tubes were slightly inclined and connected to horizontal junction boxes instead of the tubes being horizontal and connected to vertical junction boxes. Allen also patented a boiler (Fig. 45) with Gurney's U tubes, but having the fire beneath the bank of tubes, instead of in the middle, as in Gurney's boiler.

ALLEN BOILER.

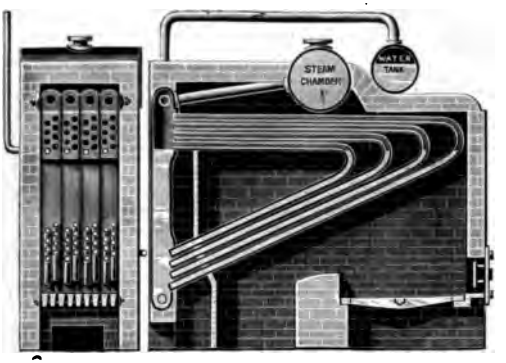


FIG. 45.

KILGORE BOILER.

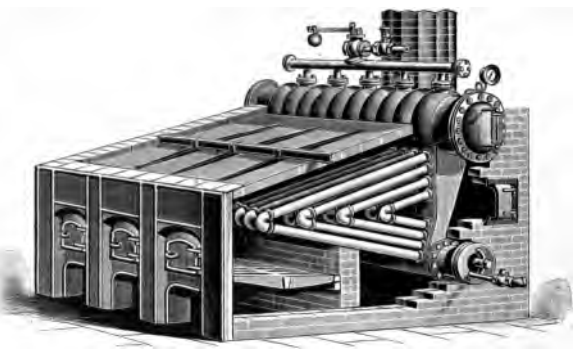


FIG. 46.

In 1871 or 1872, Commander du Temple commenced the construction of his boiler in France, it being primarily intended for aerial navigation.

In 1874 a boiler (Fig. 46), similar to Allen's 1872 boiler, was brought out by Kilgore in America, and somewhere

PLAMBECK & DARKIN BOILER.

FIG. 47.

FIRMENICH BOILER.

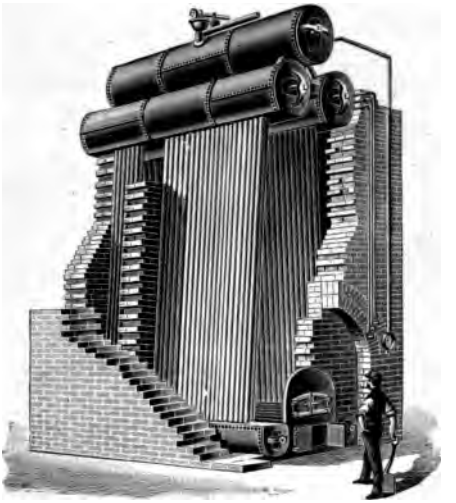


FIG. 48.

ROGERS & BLACK BOILER.

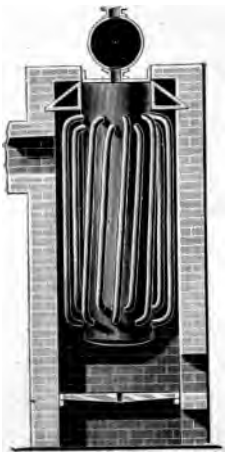


FIG. 49.

SHACKLETON BOILER.

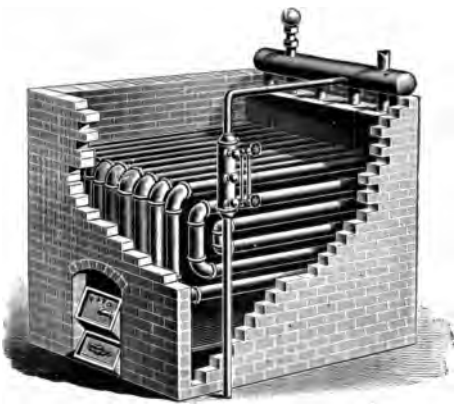


FIG. 50.

about this time Plambeck and Darkin (Fig. 47) and Fryer patented tubulous boilers.

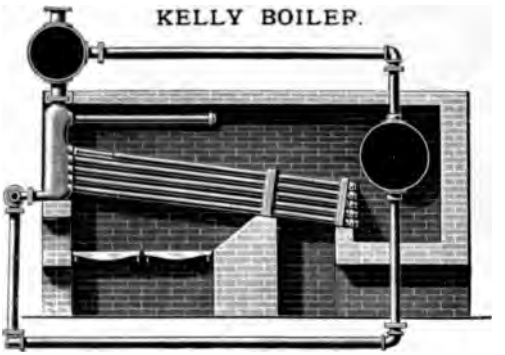


FIG. 51.

The Firmenich boiler of 1875 (Fig. 48) consisted of flat-sided horizontal drums, connected at the top and bottom of a bank of long straight tubes. Two of these units were inclined like an A, with the grate between them, and surmounted with a steam drum at the top.

HARRISON BOILER.

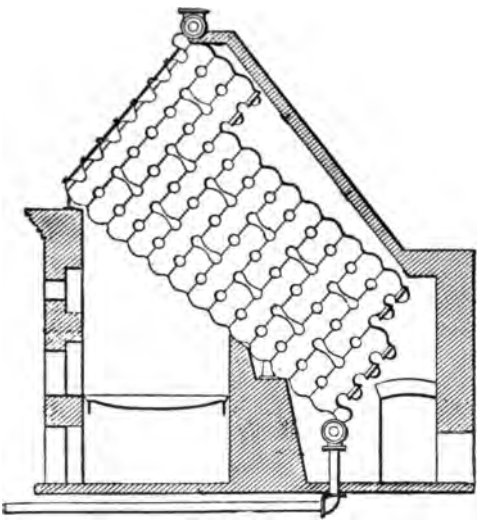


FIG. 52.

In 1876 boilers were brought out by Rogers and Black (Fig. 49), Shackleton (Fig. 50), and Kelly (Fig. 51) in America, and by Harrison (Fig. 52), and Rowan in England. The arrangement of Rowan's tubes is shown in Fig. 53. In 1877

tests were made in America on the Sinclair boiler (Figs. 54, 55), and in 1878 the Belleville boiler of 1872 was further modified by the addition of a down-take pipe to convey the water from the separator back to the feed-collector, passing through a settling tank where solid deposits could accumulate on the way.

ROWAN, 1875.

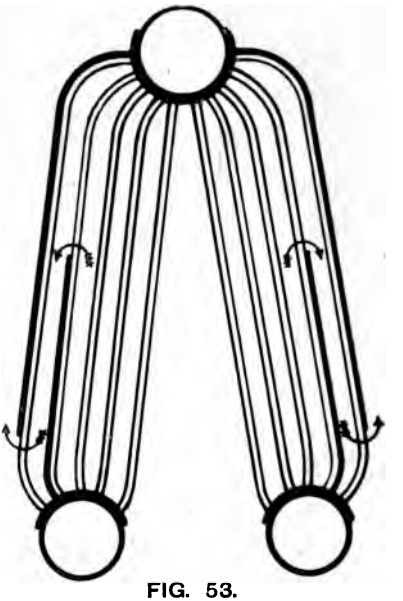


FIG. 53.

In 1878 the du Temple boiler (see Fig. 123) was first fitted on some steam launches in France. This boiler consisted of a bank of tubes bent in a serpentine form rising out of a water reservoir and surmounted by a steam and water drum. Large external down-takes were fitted to return the water from the top to the bottom reservoir.

SINCLAIR BOILER.

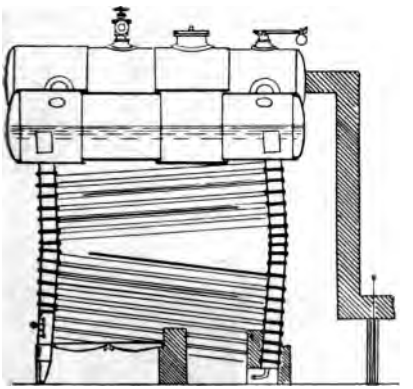


FIG. 54.

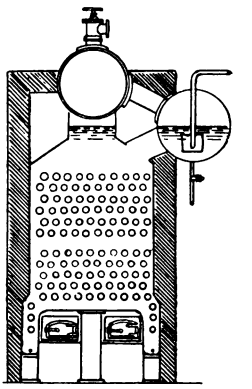


FIG. 55.

In 1878 the first experiments were made with the Niclausse boiler, which was fitted with an internal

NICLAUSSE BOILER. EARLY FORMS.

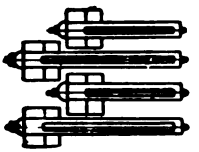


FIG. 56.

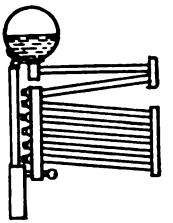


FIG. 57.

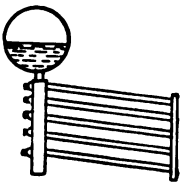


FIG. 58.

concentric tube inside a large tube, and a bolt running down the centre making a joint at either end (Fig. 56). This arrangement was not satisfactory, and the next attempt was with a header back and front, connected by a forked tube at the top to the upper steam drum, and with a pipe leading

WARD COIL BOILER.

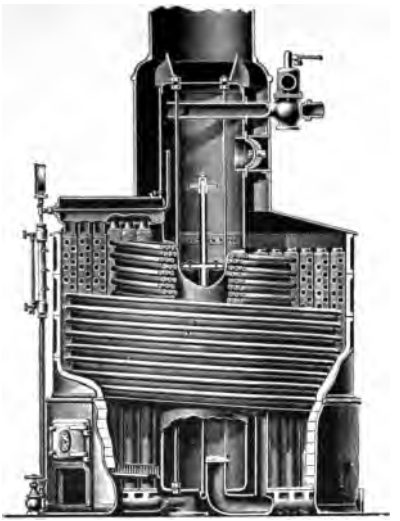


FIG. 59.

HAZELTON BOILER.

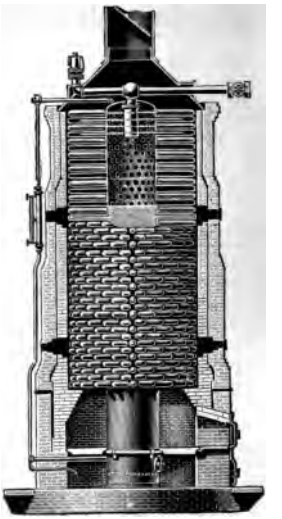


FIG. 60.

from the upper steam drum bringing the water to a horizontal bottom tube (Fig. 57). This design was succeeded

by one in which two vertical rows of tubes were connected to the same header, the down pipe and bottom feed collector being dispensed with (Fig. 58).

About the year 1879, Charles Ward in America introduced a circular coil boiler (Figs. 59 and 135), which has been used in the United States Navy.

CORLISS BOILER.

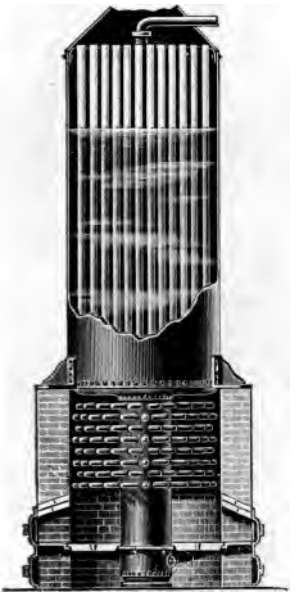


FIG. 61.

THORNYCROFT COIL BOILER.

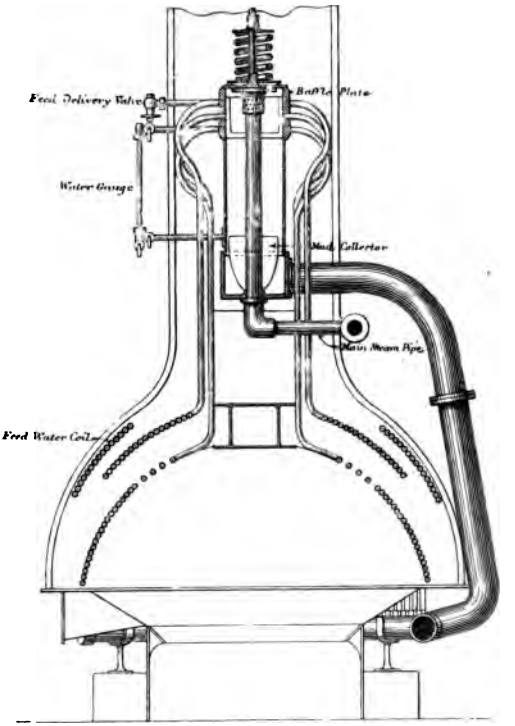


FIG. 62.

Hazelton introduced a boiler (Fig. 60) in 1881, and in the same year Heine took out a patent for his boiler (see Fig. 114).

Somewhere about 1882, Corliss in America invented a water-tube boiler (Fig. 61), and one was introduced in this year by Meissner, also an American.

About this time the Kingsley boiler, and Gill's injection boiler were brought out. Thornycroft's coil boiler (Fig. 62) was fitted on the "Peace" in 1883, and Herreshoff in America was at this time also fitting a coil boiler (Fig. 63) somewhat like Mr Thornycroft's "Peace" Boiler. In 1884, Thompson's boiler, Morrin's "Climax" boiler (Fig. 64), and Steinmüller's boiler were brought out, and Lane's (Fig. 65) in 1885.

HERRESHOFF BOILER.

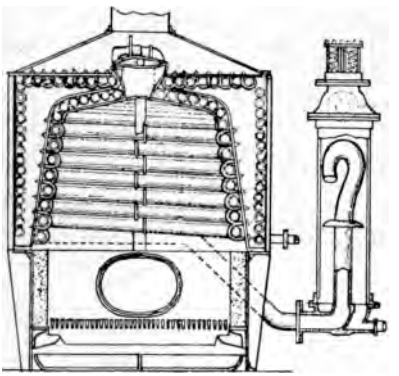


FIG. 63.

MORRIN "CLIMAX" BOILER.

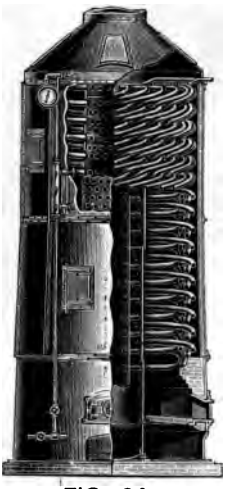


FIG 64.

We now come to the introduction of Thornycroft's water-tube boiler (Fig. 66) into the Navy in 1887, when it was fitted on H.M.S. *Speedy*. This boiler consists of two banks of very long tubes of small diameter, with the lower ends of each bank connected to separate water drums, the upper ends of the tubes being connected to the upper part of a common steam and water drum above the water level, and the tubes are curved in such a way as to form a complete arch over the fire grate. Yarrow in this year first used

straight tubes for his boiler (see Fig. 145) which, like the Thornycroft, and many other makes of small tube-boilers, has

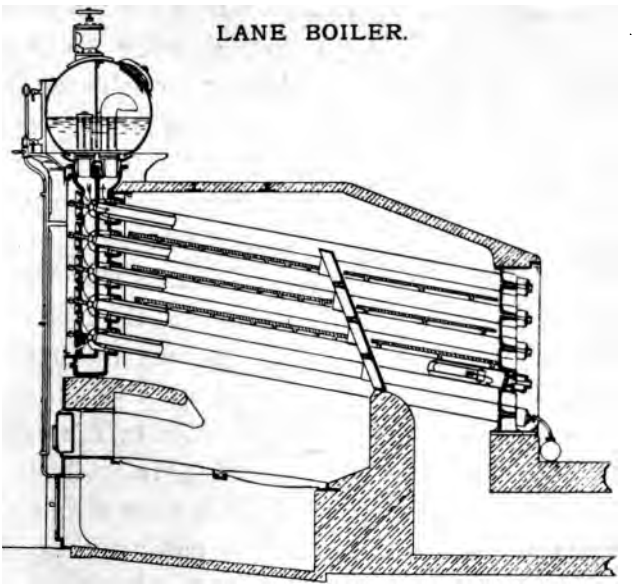


FIG. 65.

a top steam drum connected by small tubes to two bottom water drums. The Yarrow boiler is a "drowned-tube"

SPEEDY **TYPE OF THORNYCROFT BOILER**

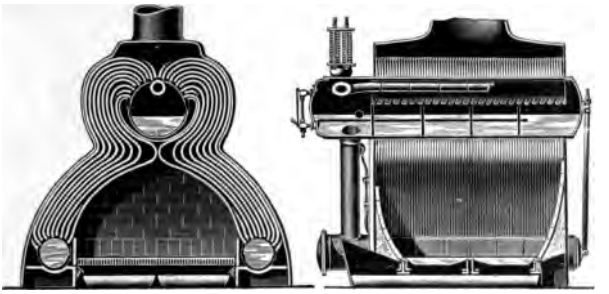


FIG. 66.

boiler, that is to say, the generating tubes enter the top drum below the working level of the water.

In 1887 Allan Stirling produced his first type of water-tube boiler (Fig. 67), which had vertical tubes depending from the top drum, and closed at the lower end, in combination with other tubes connected at the top to the steam and water drum, and at the bottom to a settling drum. This boiler was called the Field-Stirling boiler. Roberts of New York also introduced a boiler in this year (Fig. 68). In Stirling's second design of 1888 the closed-ended tubes were discarded, and two extra top drums were added, making three in all (Fig 69). The tubes coming from these drums were attached to a common settling drum at the end of the furnace.

FIELD-STIRLING BOILER.

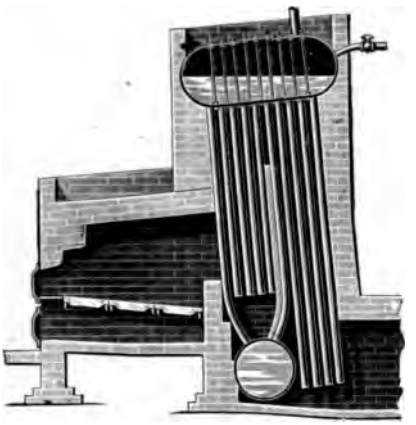


FIG. 67.

ROBERTS BOILER

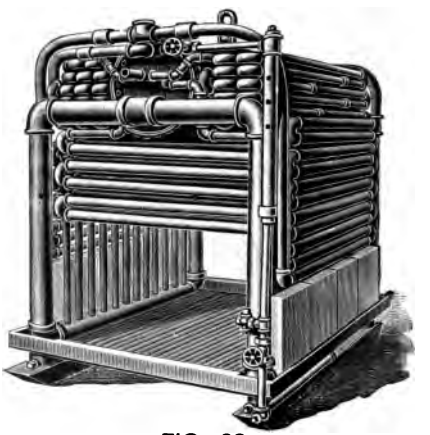


FIG. 68.

In 1889 Cowles in America patented a boiler somewhat like the Thornycroft, but with a mass of tubes at the rear of the grate. Wood introduced a boiler (Fig. 70) very similar to Maynard's of 1870.

In 1890 Messrs Niclausse took out a patent for their boiler in its present form (see Fig. 101), which consists

of inclined Field tubes connected to a upright header divided internally by a vertical diaphragm. The water from one side of the diaphragm finds its way to the internal tubes, and the steam rises on the other side of the diaphragm. The whole of the tubes could be withdrawn, cleaned, and replaced from the front of the boiler.

STIRLING BOILER.

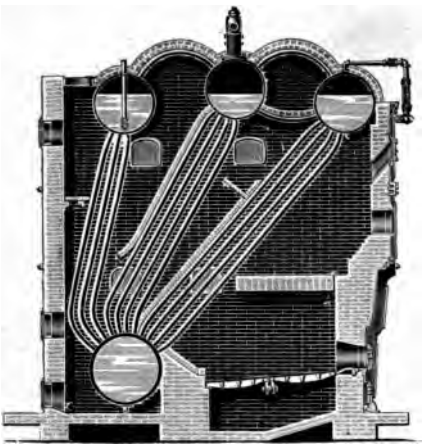


FIG. 69.

About 1890 Monsieur P. Oriolle of Nantes introduced a boiler (see Figs. 109, 110), which was fitted to some torpedo boats in the French Navy, and is still in use. Herreshoff, in 1890, brought out another form of boiler (Figs. 71, 72), very similar to the

WOOD BOILER.

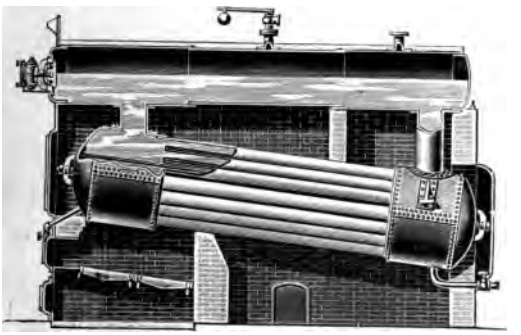


FIG. 70.

Belleville, but having a feed-water heater above the tubes made up of pipes and fittings. Almy in this year introduced a boiler (Fig. 73), made up of straight pipes, which were

connected by elbows and return bends to an overhead steam and water drum, and at their bottom ends to horizontal

HERRESHOFF BOILER.

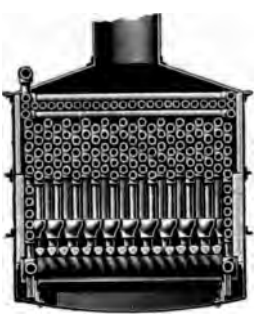


FIG. 71.

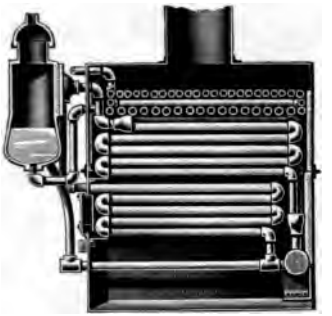


FIG. 72.

connecting pipes. Boilers were invented or brought out in 1891 by Cook, and in 1892 by Wheeler, Henshall (Fig. 74), Cahall (Fig. 75), and Mosher in America, and a new form of the Thornycroft boiler was fitted on H.M.S. *Daring* (see Fig. 121). In the early type of *Daring* boiler there was one large central bottom drum and two smaller ones for the pipes forming the side of the furnace; there were two grates, one on each side of the central bottom drum. In this year (1892) Mosher obtained his English patent for a water-tube boiler (see Fig. 131), not unlike what would result from cutting Thornycroft's

ALMY BOILER.

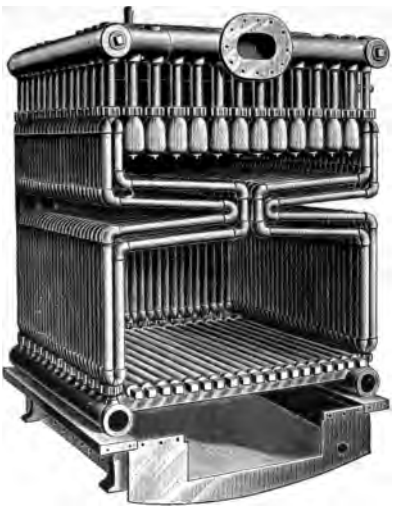


FIG. 73.

boiler in half vertically, and transposing the two halves, so that the tubes were back to back with the steam drum outside.

HENSHALL BOILER.

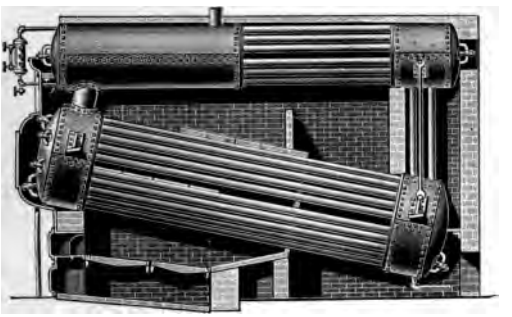


FIG. 74.

In this boiler there are two steam and water drums, one for each bank of tubes and a bottom water drum for each bank. The end of the furnace is formed by a tube wall. All the tubes deliver into the steam drum *above* the water level, as in the Thornycroft boiler.

CAHALL BOILER.

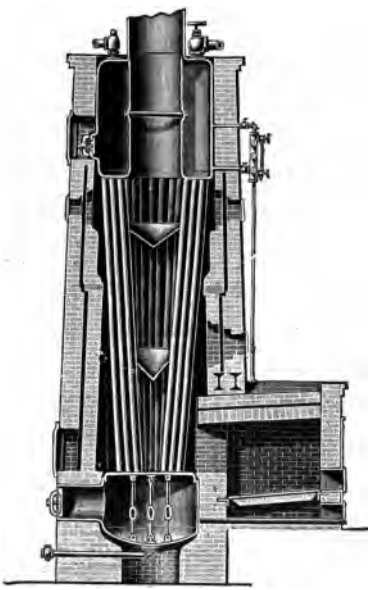


FIG. 75.

M. Normand modified and improved the du Temple boiler by reducing the number of folds and increasing the number and diameter of the tubes. These improvements ultimately led to the introduction of what is known as the Normand boiler (see Figs. 127, 128). Under this heading we might mention a further development, introduced by M. Sigaudy, which con-

sisted in placing two Normand boilers back to back, and connecting up the steam and water drums. This boiler is known as the Normand-Sigaudy boiler (Figs. 129, 130), and is intended for use on large ships.

In 1893 Hyde, and Pierpoint in America, and Blechynden, White, Reed, Anderson and Lyall and others in this country had boilers at work or in course of construction.

The Blechynden boiler (see Fig. 142) bears a very strong resemblance to the Yarrow boiler, there being no external down-takes, the water being supposed to return down the two outer rows of tubes. The tubes in this boiler are curved to arcs of different radii, which converge on two lines of hand-holes in the top of the drum. Hand-holes are studded along this drum sufficiently close to allow of all the tubes being easily withdrawn through them.

Samuel White of East Cowes has brought out a boiler (see Fig. 134), consisting of a central steam drum and two lower water drums, the drums being connected by a series of pipes coiled like helical springs. He has since discarded the use of this boiler in favour of a boiler with nearly straight tubes, known as the White-Forster boiler, and shown in Figs. 143, 144.

The Reed boiler (see Fig. 133), brought out by Mr Reed, the Manager of Palmer's Shipbuilding Company of Jarrow-on-Tyne, resembles very closely in many points the du Temple and Normand boilers. Fleming and Ferguson have brought out a form of water-tube boiler (see Fig. 141) for the heavier class of marine work, which has been called the "Clyde" boiler. Mr Seaton has also designed more than one type of boiler, but they have not been largely used.

Towne, in America, introduced a boiler (Fig. 76) which consists of narrow flat water-spaces on both sides of the furnace, connected by straight cross tubes intersecting at the centre.

Mumford of Colchester patented in 1893 a boiler of the small-tube type (see Fig. 138), in which the tubes are constructed in groups, each group being fitted at top and bottom into a box which communicates with the steam and water drums respectively.

TOWNE BOILER.

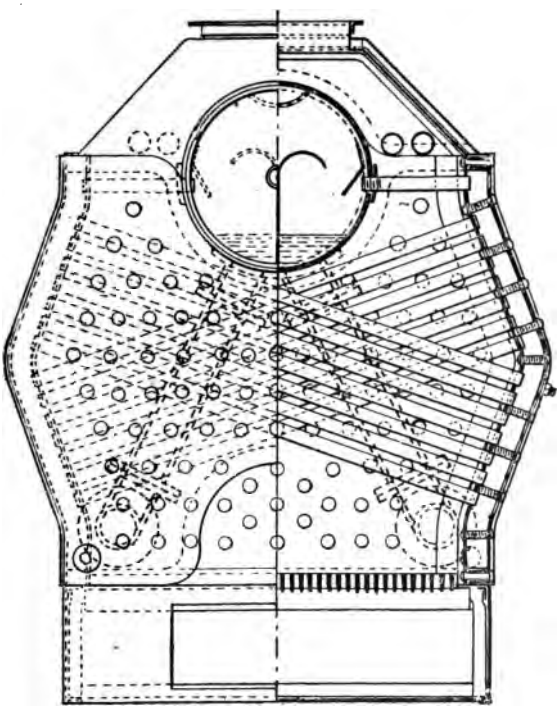


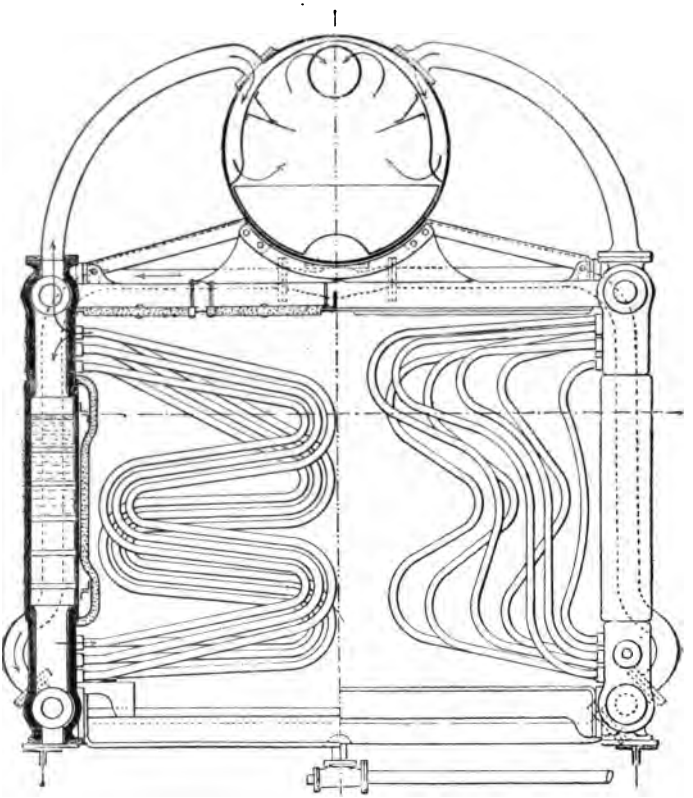
FIG. 76.

Petit and Godard also used flat-water spaces, but the small tubes on leaving the bottom of the water-space formed a zigzag over the top of the furnace, and entered the same water-space at the top above the water level (Fig. 77).

The Dürr boiler (see Figs. 105, 106) is a German boiler very similar to the Niclausse boiler, and has been fitted on several German men-of-war. Another boiler of German origin

is the Schulz boiler, patented in England in 1894. It is a small-tube boiler very similar to the Thornycroft, but has a superheating apparatus fitted above the top central drum at

PETIT AND GODARD BOILER.



Back tubes. FIG. 77. Front tubes.

the base of the uptake. It is being largely used in the German Navy.

M. Guyot designed in 1896 another modification of the du Temple boiler, which is being fitted on some of the French torpedo boats and large cruisers.

In 1896 Leblond and Caville brought out a small-tube boiler

(Fig. 78) with a single steam and water drum above, connected by small curved pipes to a water drum below. In the same year M. d'Allest designed a very similar type of boiler, except that the lower water drum was superseded by a header, into which the lower ends of the tubes were expanded.

The Babcock and Wilcox Marine type boiler (see Figs. 99, 100) differs in some respects from their land type. The highest point of the boiler is at the back, the tubes sloping downward from back to front. In the boilers fitted to H.M.S. *Sheldrake*, several small tubes were substituted for each large tube, but latterly they have returned to the use of large diameter tubes as in their land type.

LEBLOND & CAVILLE BOILER.

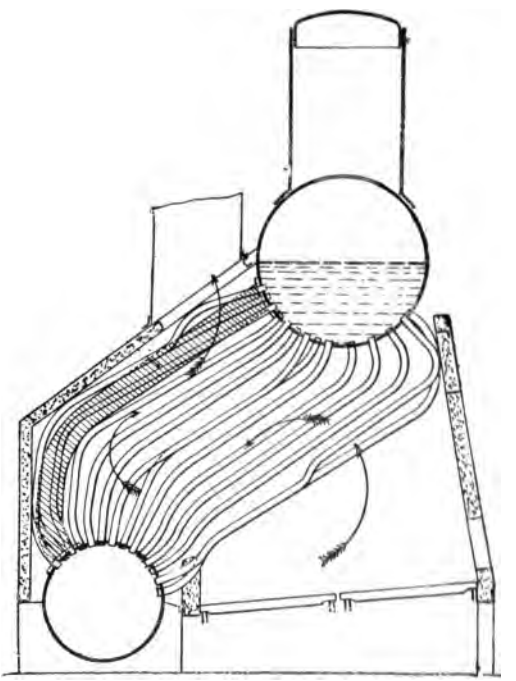


FIG. 78.

In 1896 the Belleville boiler was fitted with an economiser in the uptake (see Figs. 94, 95), the number of generator elements being at the same time reduced; this had the effect of giving an increase in economy of coal of 20 to 22 per cent. Owing, however, to the rapid deterioration of the economiser tubes, the Boiler Committee appointed by the Admiralty have recommended its disuse.

5. Early Developments of the Water-tube Boiler in connection with Road Locomotion.—Many of the early water-tube boilers were designed for the purpose of propelling road carriages, their use entailing a great reduction in the total weight of the vehicle. The earliest record we have of the adaptation of a water-tube boiler to this purpose is contained in Griffith's patent of 1821. The boiler, as actually made (Fig. 79), consisted of horizontal tubes joining flat vertical water-spaces, the furnace being between these water-spaces and directly under the tubes. The boiler, however, was not a practical success, owing to the difficulty in keeping the tube joints tight, and in keeping the boiler supplied with water by the feed pumps. The failure of the carriage was mainly due to the boiler. It may be noted that in the patent drawing the tube ends were joined by bends and not by flat water-spaces as actually constructed. In 1825 Goldsworthy Gurney brought out his road carriage, for which he designed the water-tube boiler shown in Figs. 6 and 7, and previously described. This

GRIFFITH BOILER.

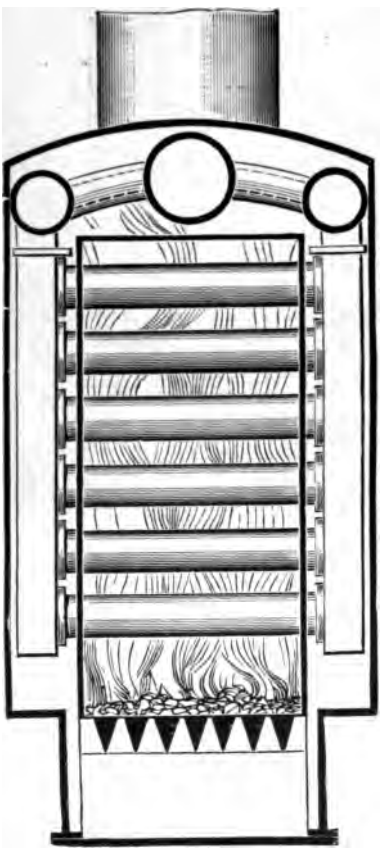


FIG. 79.

carriage was for a time very successful, a regular service being established in 1831 between Gloucester and Cheltenham.

DANCE BOILER.

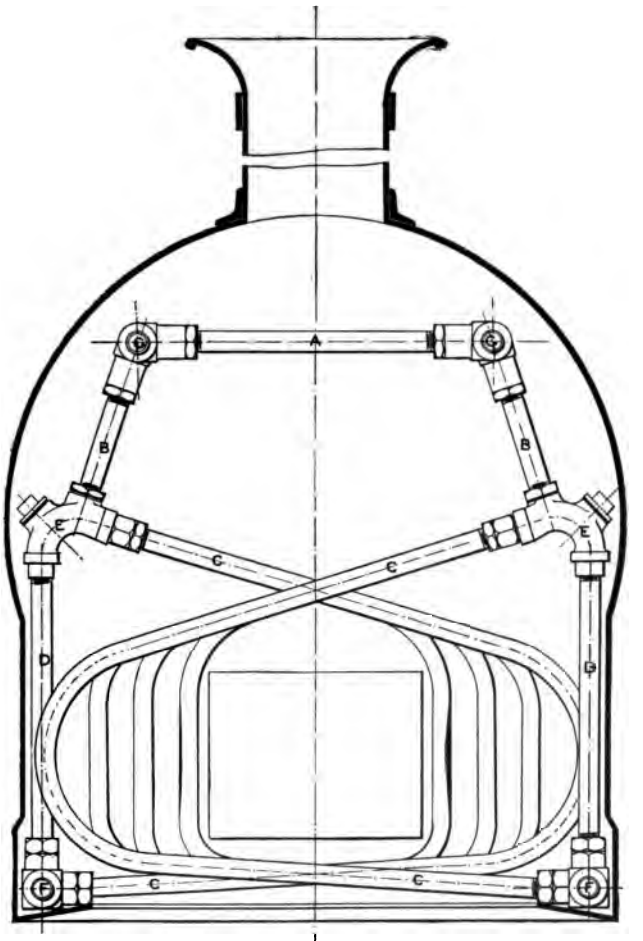


FIG. 80.

Sir Charles Dance, who bought and ran several of Gurney's coaches, however, designed a modified form of this boiler, and subsequently he designed, in conjunction with Messrs

Maudslay and Field, a tubulous boiler, with which he replaced Gurney's boiler in these coaches. Dance's boiler (Fig. 80) had two horizontal water-tubes F one on each side of the boiler, running fore and aft; vertical tubes D rose from these to a certain height, whence by means of a junction piece or bend E, they were connected to pipes C which crossed to the other side of the boiler in a downward direction, at an angle of about 45°, and on reaching that side they were bent down and then returned nearly horizontally to the water-pipe from which the vertical pipes rose. The steam got away through pipes B connected to the bend at the top of the vertical pipes, the short pipes being connected by horizontal cross-tubes from which the dry steam was taken. The running of these coaches had to be discontinued, owing to the opposition of the turnpike authorities, who put down stretches of loose road-metalling at intervals, so as to render the roads impassable; in fact, the opposition of the authorities rather than any serious mechanical difficulties may be said to have been the chief cause of the non-success of most of the early coaches designed for passenger traffic.

The next road carriage fitted with a tubulous boiler which had any practical success was that of Hancock. The patent for this boiler (Fig. 81) was taken out in 1833. The boiler was made up of flat cells or chambers A, having projections of nearly hemispherical shape upon the outside of each cell. These cells were placed side by side, so that the projections on one side touched the projections on the other, and left a space in between the cells for the flue gases. Each cell was formed of a single sheet of iron or copper, one half of the sheet at a time being hammered in a cast-iron mould to produce the projections referred to: the sheet was then bent over, and the ends riveted

together, forming a kind of bag, the end without a riveted joint being exposed to the fire. Large holes were made in the sides of each bag at top and bottom, perforated rings B, being inserted inside the bags, and unperforated rings C, outside. The bags being placed between stout wrought-iron plates GG, stay bolts E, were then passed through, and

HANCOCK BOILER.

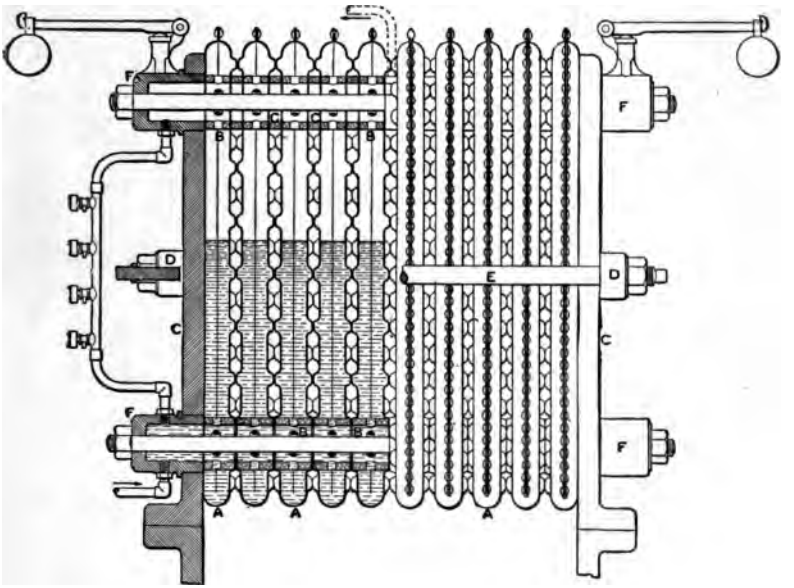


FIG. 81.

the whole drawn together. Each chamber communicated with the others through the annular space between the stay-bolts and rings.

Hancock was probably the most successful steam-carriage builder of this period. He constructed ten or eleven road carriages between the years 1824 and 1840, all of which worked with a good deal of success.

The next steam-carriage fitted with a water-tube boiler

was Summers and Ogle's (Figs. 82, 83). The vertical water-tubes were connected at the top and bottom to D-shaped tubes, and through them passed the smoke tubes. This boiler was followed by Maceroni and Squire's (Fig. 84), which was

SUMMERS AND OGLE BOILER.

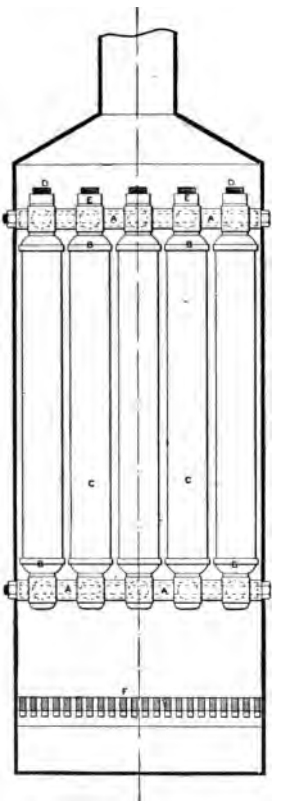


FIG. 82.

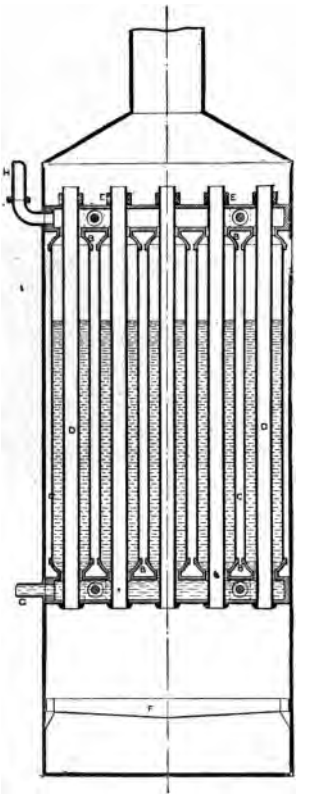


FIG. 83.

also of the vertical water-tube type, but was provided with a central steam receiver. The working pressure was 150 lbs. per square inch. Maceroni and Squire's coach is said to have run 1700 miles without repairs of any importance. Both Summers and Ogle's, and Maceroni and Squire's

coaches had to be discontinued for the same reasons that caused the withdrawal of Hancock's steam-carriages, namely, the opposition of the local authorities.

The water-tube boiler designed by Dr Church for his

MACERONI AND SQUIRE BOILER.

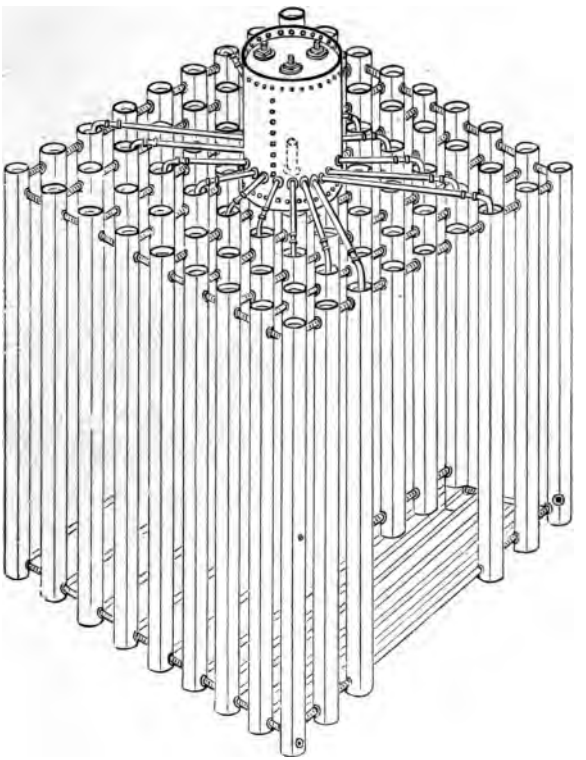


FIG. 84.

road carriages, which were built between 1832 and 1833, was also of the vertical type (Fig 85). The water-tubes descended vertically from the crown of the combustion chamber, and were turned through a quarter circle at their lower ends and connected to the annular water-space which encircled the bank of tubes. The hot gases passed vertically

up among the tubes, and escaped at the top through four pipes, which passed through the concentric water-space into the uptake. Church also patented another boiler with fire-tubes instead of water-tubes, which was to all intents and purposes his water-tube boiler turned upside down or inside out.

These boilers were the last water-tube boilers brought out especially for road locomotion, for a period of over thirty years, as Holt's carriage of 1867, Thomson's carriage of the same date, and Mackenzie's carriage of 1875, were all provided with boilers fitted with Field tubes. Loftus Perkins, however, in 1870, constructed a car running on one wheel, which was designed to be attached to the front of any vehicle. It was fitted with his water-tube boiler working at a pressure of 450 lbs., and was sent abroad, but what became of it is unknown.

CHURCH BOILER.

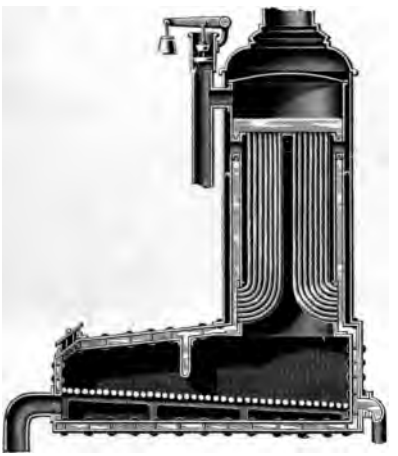


FIG. 85.

Of recent years Messrs Serpollet, Thornycroft, the Liquid Fuel Engineering Co., Coulthard, Musker, and others have been applying various types of boilers to road carriages, but they can hardly be said to come under the head of "early" developments of water-tube boilers for road carriages.

6. Early developments of Water-tube Boilers on board ship.—One of the earliest sea-going steamers fitted with

water-tube boilers was the *Thetis*, built in 1857 by Scott and Company, of Greenock, and fitted with a tubulous boiler by J. M. Rowan of Glasgow. The *Thetis* was built for experimental purposes, and, after a series of trials, was worked successfully for about a year, after which time her boilers gave trouble, the tubes ultimately failing through internal corrosion. In 1859 J. M. Rowan and T. R. Horton brought out a "cellular" boiler, which was fitted in 1860 to the *Athanasian* and some paddle steamers intended for river work in India. The boilers of these river steamers ran for ten or eleven years, and were then replaced by Rowan and Horton boilers of the *Propontis* type. The boilers of the *Athanasian*, however, had to be removed after being in use for nearly a year, owing largely to the corrosion of the tubes from the use of sea-water, and were replaced by a water-tube boiler, designed by Howden of Glasgow, who has done so much for the development of forced draught with heated air. In 1870 the *Marc Antony* and the *Fairy Dell* were fitted with tubulous boilers. They made two or three voyages, but, ultimately, both ships were lost, owing to the failure of the boilers.

Perhaps the most interesting application of tubulous boilers of this class in the early days was the case of the *Propontis*. This ship was fitted with Rowan and Horton's 1869 boiler, which is generally referred to as the *Propontis*-type boiler, though it was fitted to a steamer named the *Haco* two years before. There has always been a certain amount of mystery surrounding these boilers, but the facts of the case appear to be briefly these. The boilers fitted to the *Haco* and to the Indian paddle steamers when they were reboilered had a steam-pipe joining the two steam-drums of each boiler (Fig. 86), and this pipe is shown in the patent drawings. On the *Propontis*, however

(Fig. 87), this connection was for some reason omitted, and the failure of the boiler was largely due to this. Mr Rowan, senior, died before the boilers were completed, and the importance of this connection was not apparently realised by any one who had to do with the boilers. In consequence of this omission, the water-level in the two sections of the boiler fluctuated considerably, and, as the water drums were connected while the steam drums were not (except by the main steam-pipe), any rise of pressure in one section of the boiler forced the water out of it into the other section. The first voyage of the *Propontis* was from Liverpool to the Black Sea and back. The boilers were fed with distilled water, the working pressure ranging from 130 to 140 lbs. The tubes, however, pitted badly, and were continually giving out, being temporarily repaired by binding a ligature round the tube over the hole. Owing to this cause, one of the four boilers was almost constantly disconnected.

ROWAN AND HORTON BOILER, 1869.

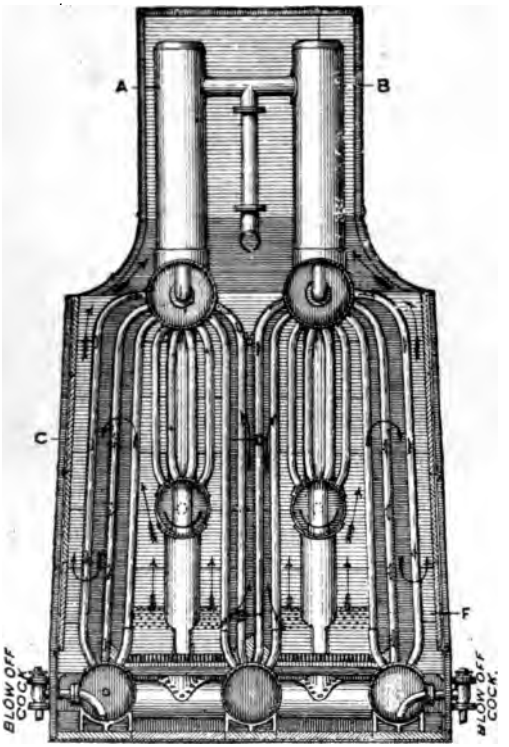


FIG. 86.

The boilers were repaired in 1875, some 300 new tubes being inserted, and were tested cold to a pressure of 250 lbs. On the next voyage, a small quantity of salt water was added as "make-up," and when the boilers were opened up

ROWAN AND HORTON BOILER OF *PROPONTIS*.

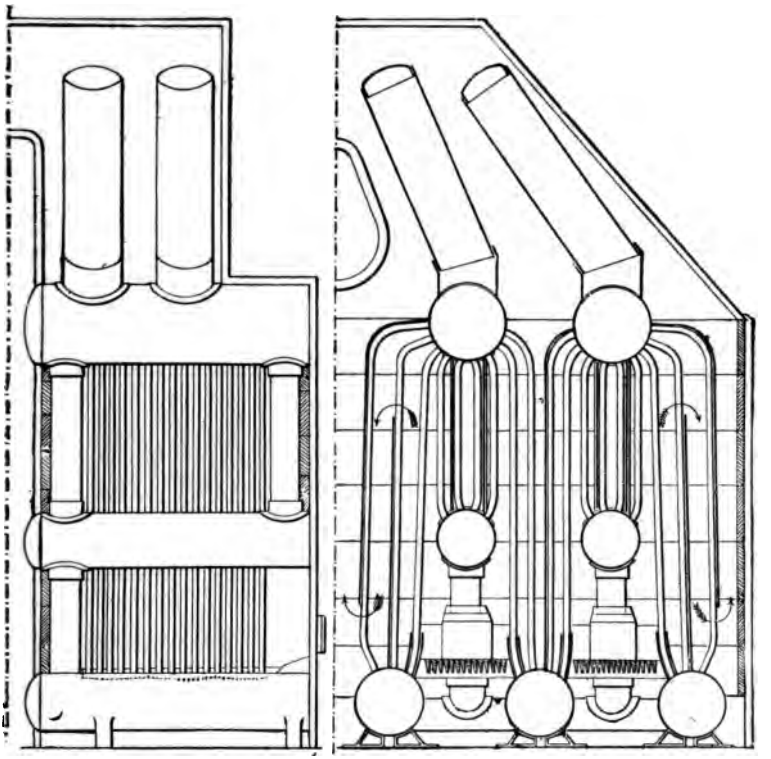


FIG. 87.

at the end of the voyage a slight amount of scale was found in the tubes. In September 1875 the wing chamber of the forward starboard boiler burst, though the pressure at the time was only 150 lbs. This chamber was patched at Lisbon with $\frac{3}{8}$" plate. A short time afterwards another explosion took place, this time on one of the after boilers,

the pressure in the boiler being 105 lbs. The drums which gave way were 21″ diameter, ⅜″ thick, and were *uncorroded*, so that the failure was probably due to shortness of water or overheating. After the explosion the small tubes were found to be thickly coated with scale, owing to the use of salt water in the boilers. Mr F. J. Rowan, the son of the inventor, states that this scale was purposely formed during the last voyage of the *Propontis* to try and stop the pitting of the tubes and enable the vessel to come home.

In the light of modern express boilers, with their extremely long and small diameter tubes, the opinions expressed at the time with regard to the tubes of Rowan and Horton's boiler are very interesting, as showing the change of practice which a few years may produce. Their vertical tubes are referred to as "*too attenuated*," being 8 feet long and 2½″ diameter. Quite a large tube to modern ideas.

In 1876 the *Montana* and *Dakota* of the Guion Line were fitted with water-tube boilers similar to the Perkins boiler (Fig. 16), but the vertical necks which join the horizontal tubes were much smaller in relation to the capacity of the boiler. The *Montana* left the Tyne with eight boilers, but before she got to the Isle of Wight six of these boilers had burst. She was towed into Plymouth, and, after repair, continued her journey to Liverpool. It was found during the voyage that the lower tubes contained steam only, and not water. The Board of Trade refused to certify the boilers, and a Commission was appointed, in conjunction with the Admiralty officials, to test the boilers on a six days' trip on the Atlantic, but the boilers proved so unsatisfactory that they had to be taken out.

These may be said to be the last of the early attempts to introduce water-tube boilers for service afloat, and for

some considerable time after this no serious trials of water-tube boilers were made in this country, the ordinary marine-type Scotch boiler being exclusively used. In France the Belleville boiler, which since 1856 had been undergoing repeated alterations, had, in 1878, attained to practically its present form, and in 1880 was tried successfully in the French Navy on the *Voltigeur*, and has since become extensively used.

CHAPTER II

Circulation in Water-Tube Boilers—Necessity of rapid circulation in Water-Tube Boilers—Rate of transmission of Heat—Corrosion—Combustion—Most advantageous arrangement of Furnace and Tubes—Ratio of Heating Surface to Grate Surface—Efficiency of Heating Surface—Variation in value of Heating Surface according to position—Rate of Combustion—Forced Draught—Advantages of Forced Draught—Adaptability of Tubulous Boilers to Forced Draught—Tests, and results obtained.

7. Circulation in Water-Tube Boilers.—Professor Watkinson in his paper before the Institution of Naval Architects in 1896, summed up the causes of circulation in these words:—

"The causes of circulation are as follows:—

"(1) The difference in density of the water due to difference in temperature when the fires are first lighted. This circulation is very sluggish.

"(2) When the water is all at approximately the same temperature, and steam is being generated, but not with sufficient rapidity to cause a break in the continuity of the water, a much more vigorous, but mainly local circulation is set up by the entraining action of the bubbles of steam rising through the water.

"(3) When steam is generated with such rapidity, that in some part of the circuit there is steam or foam *only* present, a very rapid circulation takes place, due to the difference in density between this steam or foam, and the continuous water in the down-comers, internal or external."

That circulation is partly due to the bubbles of steam dragging or entraining the water with them when steam is being slowly generated, may be shown by introducing air through a pipe into one of the legs of a U-tube, when it will be seen that a very slow circulation is set up. Mr Yarrow made a very curious and interesting experiment on this in January 1896. The arrangement is shown diagrammatically in Fig. 88. He connected an air-pipe, which could be shut off with a cock, to the lower portion of each of the legs of a U-tube, the upper ends of which communicated with a water-drum C, from which the tube hung vertically down. The ends of the air-pipes communicated with a reservoir holding air under pressure. On admitting air from one of these pipes E into one leg A of the U-tube, circulation was established in an upward direction in that leg, and consequently in a downward direction in the other leg B, and was increased by opening the cock F, the bubbles of air from the second cock passing downward and rising in A. On shutting off the cock connected to A, the circulation still went on in the same direction.

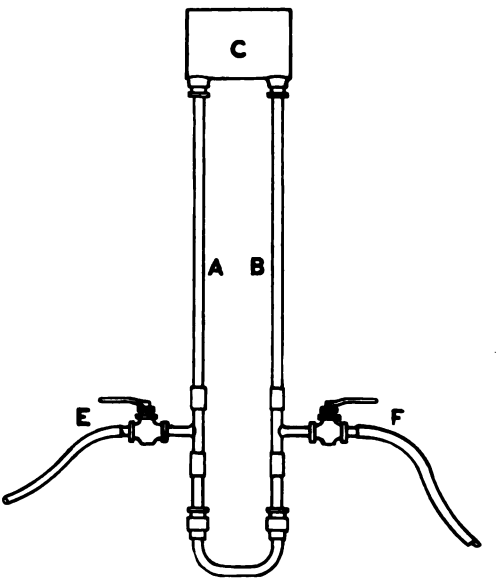


FIG. 88.

The circulation in the Belleville boiler is comparatively

sluggish. The water is forced into the lower tubes through a non-return valve, which effectually prevents the water being driven back by the steam up the down-comers and into the steam drum. The action is intermittent, as in all cases where the discharge from the tubes takes place above the water level, plugs of water and steam being pushed forward into the steam drum. In warming up rapidly there is a water-hammer action, owing to the form of the end boxes, which are contracted, and also to steam being generated in several of the lower tubes at once. Steam formed in the lowest tube forces the water into the upper tubes; the steam formed in the upper tubes tries to push this water back into the lower tube, at the same time forcing the water before it into the steam drum.

In boilers with "free circulation," such as the Niclausse, and Babcock and Wilcox, the circulation is partly due to the entraining action of the bubbles moving through the inclined tubes, but mainly to the difference of density that exists between the column of foam in the heating-tubes and the solid water in the down-comer.

We pass now to the consideration of circulation in the boilers of the small-tube type, or those having "accelerated circulation." These may be divided roughly into two classes:—(1) Those with tubes delivering above the water-line, and (2) Those with tubes delivering below the water-line. Boilers of the latter class are usually distinguished by the name of "drowned-tube" boilers. In the "drowned-tube" type, such as the Normand, Yarrow, and Blechynden boilers, the water flows up the tubes nearest to the fire and down those more remote from it. Mr Yarrow at first employed an external down-comer of large diameter, the upward movement taking place in the small tubes. Subsequently, he found that this down-comer was unnecessary,

as many of the small tubes acted in the capacity of down-comers.

During Mr Yarrow's experiments on circulation, referred to above, he also employed a metal water drum A (Fig. 89), from the bottom of which two glass tubes, B and C, projected vertically downward, being united at the bottom by a copper bend D. He had six bunsen burners arranged at different heights, three being employed to heat each tube. Each of these burners could be used separately. On the top of the drum he arranged a balance, one arm being suitably loaded and the other having attached to it by a thread an ebony bob F, which was suspended in the down tube in such a way that water when flowing downwards caused it to descend. A pointer was fixed to the balance by means of which readings could be obtained on a scale. On lighting the two lower burners, B_1, B_2, of the up tube B, circulation commenced, and the ebony bob F descended, causing the pointer to travel over the scale. On lighting the third burner B_3, the circulation increased. When the burners for heating the down tube C were lit (the others still being alight), it was found that the circulation *still further increased*, and, in the experiments under pressure, when those on the up tube B were turned off, the circulation still went on, and in the same direction. By means of a small screw propeller,

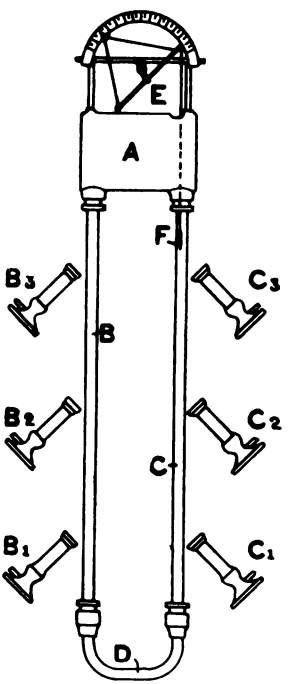


FIG. 89.

fitted in the down tube and attached to a vertical spindle, Mr Yarrow was able to obtain some measure of the velocity of the circulation.

He made some further experiments, by adding a third tube, G (Fig. 90), taken off by means of a T from the bend between the two vertical tubes, and passing up to the bottom of the top drum *outside* the gas furnace which he was using for heating these tubes. When circulation was once started, it was found that heating the external down-comer had the effect of accelerating the circulation. From these experiments, Mr Yarrow found he could dispense with external down pipes without hindering the circulation in his boiler.

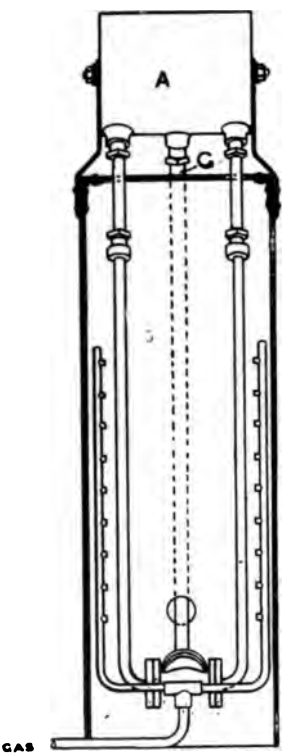


FIG. 90.

In the Thornycroft boiler, the tubes of which deliver above the water level, when a certain rate of evaporation is exceeded the discharge of steam and water is intermittent, plugs of water being discharged from the tubes at intervals. At high rates of forcing, however, the action is more nearly continuous. This is more especially the case in the "Daring" type of boiler, which has internal heated down-comers, the circulation being very active.

The inclination of the tubes in a boiler has a marked effect on the circulation. With boilers taking the water from a bottom water drum, and discharging directly into a

steam drum, the circulation increases in rapidity as the tubes approach the vertical, provided that the ratio of length to diameter is not too great. With tubes discharging into, and taking their water from, vertical headers any inclination between 10° to 15° from the horizontal, does not appear to materially affect the circulation. When the tubes are nearly horizontal the only safe way to prevent the water being driven out of them is to use a non-return valve and restrict the opening at the lower ends of the tubes. This is done in the Belleville boiler.

To ensure a proper circulation in a small tube boiler and prevent overheating, the following conditions must be observed.

1. Direction of tubes, especially at their lower ends where nearest the fire, should be as nearly vertical as possible.
2. Circulation must be very active.
3. Ratio of length to diameter must not be too great.
4. Section of down-comer must be sufficiently large.

The failures that have occurred in some types of water-tube boilers have been caused through these points being disregarded.

8. Necessity of rapid Circulation in Water-tube Boilers.—It will be abundantly evident that rapid and constant circulation is an absolute necessity in water-tube boilers. The areas through the different elements are often so small, and the volume of water so limited, that with fierce fires and rapid rates of combustion, steam is very quickly generated, and unless it can get away freely, steam pockets will be formed. Should this occur, there will be no water present to absorb the heat, the metal will become locally over-heated, and the tube may be burnt. The only way to prevent this is to provide the steam with a ready

means of escape, and at the same time to ensure a plentiful supply of water to take its place.

9. Rate of Transmission of Heat.—It is not possible in these lectures to take up the physical aspect of the rate of transmission of heat through the metal of a boiler plate or tube. The natural laws underlying the transmission of heat will be the same whatever the class of boiler. Very little is actually known of the laws relating to the transmission of heat from the hot gases to the metal of the water-tubes, and from the metal walls to the water. It is, however, known that the heat is transmitted very slowly by conduction, that is to say, transference of heat from one particle of water to another particle of water; and that by far the greater portion of it is transmitted by convection, that is, bringing the particles of water in contact successively with the heated metal, and this exemplifies the need of rapid circulation. Mr Blechynden made some interesting experiments on this subject, which were communicated to the Institution of Naval Architects (1896); M. Henry, of the Paris-Lyon-Mediterranée Railways, made some experiments on the efficiency of the heating surface in relation to its position in the boiler;* and Sir John Durston, the Engineer-in-Chief of the Navy, also made some experiments on this subject, the results of which were communicated to the Institution of Naval Architects (1893).

It has been demonstrated that the heat passes far more readily between the water and the metal than between the hot gases and the metal. If, therefore, some obstructing cause, such as boiler scale, prevents the passage of the heat to the water, over-heating of the metal must result. This explains how necessary it is when working

* "Marine Boilers," L. E. Bertin, p. 130.

at light rates of evaporation to keep the internal surfaces of the tubes clean, as it is well known that boiler scale is one of the most inefficient conductors of heat in existence.

10. Corrosion.—A very general cause of wear in boilers is oxidation, due to contact with air and water. Pure water does not attack iron except in the presence of air. Neither pure water exhausted of air, nor dry air alone, have any chemical effect on iron, but if air be present in the water, pitting is certain to take place. The pitting action is, however, more severe if carbonic acid is present, and more energetic still with certain chlorides, especially chloride of magnesia; and as sea-water contains this salt of magnesia, it should never under any circumstances where it can possibly be prevented, be admitted to the boiler. If the density of the sea-water is sufficient, hydrochloric acid is liberated at 212° Fahr. but even in a weak solution, after a temperature of 248° Fahr. is realised (corresponding to a pressure of 28 lbs. per square inch), this acid is given off. It follows therefore that in high-pressure boilers in which the temperature is considerably over 248° Fahr. the use of sea-water as "make-up" should be absolutely prohibited. Belleville suggested the use of lime as a reagent, so as to permit of the use of salt water to replace the loss of fresh water, and with good results. The use of lime is still continued, but the employment of sea-water has been abandoned.

Another fruitful source of corrosion is the presence of fatty acids produced by the decomposition of animal or vegetable oils, used in lubricating the cylinders and other parts of the engines.

These oils are all chemically composed of glycerine and a fatty acid. They are readily decomposed into their component parts at a temperature above 212° Fahr. In con-

sequence of this, the glycerine is all separated out in the steam cylinders, and the fatty acids are carried on into the boilers, where they at once proceed to attack the metal, the resultant compound being "ferric soap," which forms the greater part of the greasy sediment to be found in some boilers. Recourse was had at one time to the injection into the boiler of carbonate of soda. This has the effect of neutralizing the fatty acids, the acids displacing the carbonic acid in the carbonate of soda. On the other hand, it was found that the carbonate only neutralized the fatty acids after corrosion had set in, and that the carbonic acid liberated had a pernicious effect of its own, as has been stated. Carbonate of soda is no longer in use, the only reagent still employed being lime.

Pure mineral oils, which are now being largely used, consist only of carbon and hydrogen, and these are chemically harmless; the addition of soda in this case would be unnecessary.

Mineral oils deposited on a boiler plate, however, form a brown varnish which is a very bad conductor of heat, and readily gives rise to overheating of the metal. In Sir John Durston's experiments * made in 1893, with a temperature of fire varying from 2,190° to 2,500°, the temperature of the metal at the bottom of an iron vessel half an inch thick when the surface was clean was 280°. On mixing 5 per cent. of mineral oil with the water it rose to 310°, and when the bottom of the vessel had a coating of grease $\frac{3}{64}''$ thick it rose to 518°.

11. Combustion.—The question of combustion in water-tube boilers is all important, and as in many instances the course of the gases through the boilers is very short, it is of

* "Transactions of Institution of Naval Architects," vol. xxxiv. p. 130.

great consequence that combustion should be as complete as possible before entering the tubes, and that the tubes should be so placed as to abstract the greatest quantity of heat from the gases.

The points to be borne in mind are the following :—

1. The grate area should be as large as possible.

2. The volume of the furnace over the bars should be as great as possible, so as to ensure the proper mixing of the gases before entering the tubes.

3. Sufficient air must be introduced below and above the grate to ensure complete combustion.

4. Gases must not enter the nests of tubes before combustion is complete.

5. Gases should be forced to remain as long as possible in contact with the tubes.

The amount of air necessary to ensure complete combustion is 143.5 cubic feet of air per lb. of coal burnt, on the supposition that the coal contains 85 per cent. of carbon and 5 per cent. of hydrogen, the remaining parts being made up of other constituents including oxygen.

When combustion is complete, all the hydrogen in the coal combines with the oxygen in the air to form steam ; and the carbon in the coal combines with the oxygen in the air to form carbon dioxide or carbonic acid gas (CO_2).

1 lb. of carbon completely consumed evolves 14,500 B.T.U.

1 lb. of carbon burnt to carbon monoxide evolves 4,400.

If the carbon monoxide meets with further oxygen, and combustion is completed, the remaining 10,100 B.T.U. are evolved.

In actual practice coal requires for its complete combustion a considerably larger quantity of air than is theoretically necessary, though the precise amount required in excess is unknown. In some experiments, made in 1877

on a cylindrical tubular boiler, the ratio of the quantity of air actually supplied to that theoretically necessary was 2.5 with natural draught when burning 20.5 lbs. of coal per square foot of grate; 2 with forced draught when burning 30.75 lbs., and 1.75 for a combustion of 41 lbs. per square foot of grate.

The reason for this excess of air is pointed out by Mr Milton in his paper before the Institution of Civil Engineers, in 1896. As the mixing of the gases, though rapid, is not instantaneous, time and space must be allowed for their proper admixture; but as they are hurried through the boiler at a very rapid rate (the total time not occupying more than $\frac{3}{4}$ second in some instances), considerable excess of oxygen must be allowed to ensure all the carbon being combined, or, in other words, to ensure combustion being complete.

This is why considerable advantage has been found in admitting air above the grate, as, though diminishing the draught above the grate and, in consequence, the passage of air through the coal, and, therefore, the amount of coal burnt, it ensures the more complete combustion of the coal, and appreciably increases the power of the boilers.

While it is necessary that there should be a certain excess of air admitted to the furnace over and above the amount theoretically necessary to ensure complete combustion, it should be borne in mind that every pound of air over and above that necessary, carries off with it a considerable amount of heat. The temperature of the unignited gases must not be lowered below the temperature of ignition before ignition is complete, or considerable heat will be lost.

The proportion of heat actually utilized in a boiler may be estimated when the temperatures of the furnace and the outgoing gases are known. If, for example, the furnace

temperature is 2,910°, which is a maximum value, and the temperature of the outgoing gases is 570°, which is a minimum value, when the temperature of the water and steam is 390°, the loss of heat is then $\frac{570}{2910}$, or 18.75 per cent., and the boiler has an efficiency of 81.25 per cent.

12. Most Advantageous Arrangement of Furnace and Tubes.—The relative position of the heating tubes to the furnace is a matter of considerable importance, and, from a thermal point of view, the following is briefly the most advantageous arrangement:—

1. The grate should not be too small for a given size of boiler, more particularly if the boiler is to be worked through large ranges of power.

2. The tubes should not be too close to the furnace. The larger the mixing chamber the more perfect the combustion.

3. A certain proportion of air should be admitted above the grate; and if this air can be warmed, so much the better. Its admittance should be transverse to the direction of flow of the hot gases. The correctness of the principle enunciated was well exemplified in some experiments on a small-tube boiler, where an increase of 12 to 15 per cent. was obtained by blowing air into the furnace transversely to the direction of the hot gases by means of air jets above the grate.

4. As large a surface of the tubes as possible should be exposed to the direct radiation of the furnace, as by far the greater proportion of the whole evaporation is done by those tubes so exposed.

5. The tubes should be so arranged as to split up the gases as much as possible.

13. Ratio of Heating Surface to Grate Surface.—The best proportion of heating surface to grate surface depends

largely on the class of boiler; the way the tubes are arranged; and the rate at which the boiler has to be worked. There are, however, acknowledged limits above which and below which it is not advisable to go. With natural draught for a combustion of 12 to 22 lbs., or slightly above this, the ratio should be about 35. With forced draught for a combustion up to 50 lbs., 45 to 50 is a good ratio. Little can be gained by increasing the ratio above this, and the quantity of water a boiler will evaporate is not directly dependent on the amount of its heating surface nor the amount of coal the grate will burn.

14. Efficiency of Heating Surface.—The efficiency of a heating surface may be roughly defined as its capability for absorbing the heat contained in the gases and transmitting it to the water. It varies through wide ranges and depends mainly upon—

1. Proximity of the heating surface to the furnace.

2. Upon the cleanliness of the sides next to the water and the fire.

Heating surface may vary enormously in value, and therefore the boiler with the greatest amount of heating surface is not necessarily the most efficient water evaporator or steam producer. The surfaces immediately exposed to the direct radiation of the furnace are the most efficient, nearly 40 per cent. of the total evaporation of a boiler being effected through these surfaces, and therefore a well-designed boiler should have the maximum amount of surface exposed to the direct radiation of the gases.

Dirt or deposit of any kind, whether external or internal, greatly reduces the efficiency of the heating surface, and should be studiously avoided. For this reason vertical heating tubes are better than horizontal, as dust and sediment

accumulate respectively on the top of the outside of the tube and on the bottom of the inside. Heating surface that is transverse to the normal path of the gases is usually considered more efficient than that which is parallel to it.

15. Variation in Value of Heating Surface, according to Position.—In any tubulous boiler consisting of rows of tubes placed one row behind the other, it is obvious that the tubes with which the hot gases first come in contact must be more efficient than those which are next encountered, as the gases have then parted with some of their heat, and

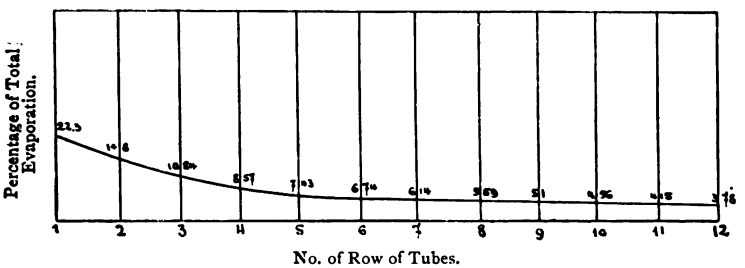


FIG. 91.

the succeeding tubes are also partially screened by the rows of tubes preceding them. The percentage of the total evaporation for which each row of tubes is answerable has been the subject of some interesting experiments by Messrs Niclausse, and the curve (Fig. 91) shows the results obtained. The tests were carried out, at atmospheric pressure, on a full-sized experimental boiler fitted with their form of generating tube, which consists of a closed-ended tube, with a smaller concentric water-tube fitted inside, and coming nearly to the bottom of the external tube. The water is delivered down the central tube and converted into steam in the external one.

The rows of tubes were "staggered" or so placed that

every second row came between the spaces in the first. The ratio between the total heating surface and the grate was 30. The tests, which were made with varying rates of combustion, ranging from 10 lbs. to 61 lbs. per square foot of grate, lasted eight hours each.

The curve (Fig. 91) shows the mean results of the experiment, and the table below gives the actual evaporation of each row.

The	1st	row of tubes	evaporated	22.3%	of the total water	evaporated.
,,	2nd	,,	,,	14.8	,, ,,	,,
,,	3rd	,,	,,	10.84	,, ,,	,,
,,	4th	,,	,,	8.57	,, ,,	,,
,,	5th	,,	,,	7.43	,, ,,	,,
,,	6th	,,	,,	6.74	,, ,,	,,
,,	7th	,,	,,	6.14	,, ,,	,,
,,	8th	,,	,,	5.53	,, ,,	,,
,,	9th	,,	,,	5.1	,, ,,	,,
,,	10th	,,	,,	4.56	,, ,,	,,
,,	11th	,,	,,	4.15	,, ,,	,,
,,	12th	,,	,,	3.78	,, ,,	,,

It will be seen from this table that the first four rows of tubes evaporated 56.51% of the total water evaporated.

16. Rate of Combustion.—The rate of combustion of coal on a grate with natural draught but with different heights of chimney varies practically as the square roots of the heights of the chimney above the grate. Thus to double the combustion in any boiler with a certain height of chimney, the chimney would have practically to be four times as high. There is, consequently, with natural draught, a limit beyond which it is impossible to go, and which is soon reached under the conditions prevailing afloat: in consequence of this, *forced draught*, that is to say, accelerating the draught by some other means than increasing the height of the chimney, has had to be resorted to at sea.

17. Forced Draught.—The advantage of some method by which the intensity of combustion could be increased, had been recognised from very early times. Between 1830 and 1850 Stevens in America tried various systems of induced and forced draught, including the closed stokehold system in 1846. In 1861 Isherwood fitted several gunboats with closed stokeholds. In 1866 the American frigates had been fitted with centrifugal fans, blowing into the ashpans, and Thornycroft, in 1876, fitted the steam-yacht *Gitana* with a closed stokehold.

At first the most general system was to cause the draught by means of steam jets in the funnel, or beneath the grates. On the introduction of tubulous boilers, however, the necessity of economising fresh water led to the substitution of air for steam.

Thornycroft may be said to have definitely introduced the closed stokehold system into the British Navy, when he employed it on his torpedo boats, and, since 1882, when it was fitted to the *Conqueror* and *Satellite*, it is practically the only form of forced draught that is employed in the British Navy. The other two systems of forced draught employed afloat (principally in the Merchant service) are "the closed ashpit system," in which the fans, instead of forcing air into a closed stokehold, force it directly beneath the grate; and the "induced draught system," in which the increased draught is caused by fans placed in the uptake. The former of the two is the system in most general use in the Mercantile Marine at the present time.

Dealing first with the "closed stokehold system," one of the principal objections to this is the necessity for the provision of air-tight castings, air-locks, and double doors, in order to hermetically close the stokehold. On the other hand, this system lends itself very well to Naval require-

ments, as for these it is necessary that the openings down to the engine and boiler-rooms should be kept as small as possible, and the machinery department would, in any case, be closed down, and air supplied artificially during an engagement. One of the advantages of the closed stokehold system is that it reduces to a minimum the risk of any escape of smoke and flame into the stokehold, as the draught is all inward towards the fire.

With the form of forced draught, known as the "closed ash-pit system," the air is forced into the ash-pit by means of a fan. In Howden's system, the air is heated in a heater attached to the boiler front before passing into the ashpit. This system has been very successful in the Merchant service with Scotch boilers, though it is not used in the Navy with tubulous boilers.

"Induced draught" is obtained by placing fans in the base of the funnel, whereby a partial vacuum is caused in the furnace: the action being similar to that caused by a very high chimney. In this case, the stokeholds are quite open, and the stokehold temperature much lower than in the case of closed stokeholds; the stokers work more comfortably, and, in consequence, the stoking is better. There are two systems of induced draught; that known as the "Martin" system, in which the air is drawn freely from the stokehold; and the "Ellis and Eaves" system, which is practically the same, except that in this case the air is heated by the waste gases before being introduced into the furnace.

Experiments were made by the British Admiralty in 1890, on a boiler of H.M.S. *Polyphemus*, as to the relative advantages of forced draught. The boiler on which the experiments were made was, however, a tubular boiler and not a water-tube boiler. The same boiler was used for both tests, induced draught being first employed and then dis-

mantled to give place to forced draught. The results were as follows:—

	Duration. hrs.	Lbs. water per lb. coal from and at 212°.	Lbs. of coal per sq. ft. G.S.	Lbs. of water per sq. ft. G.S. from and at	Approximate I.H.P.
Induced draught .	96	11.13	40.4	450	426
Forced ,, .	96	9.3	47.3	444	395

The necessity for the use of some kind of forced draught on board a ship makes itself felt mainly in three directions: *first*, the necessity of obtaining greater evaporation, and therefore larger powers for a given weight of boiler; *secondly*, the frequency on board a war-ship of sudden calls for a large increase of power in a comparatively short space of time for manœuvring purposes; and *thirdly*, for ensuring sufficient draught on small craft with a very limited height of funnel. It was only possible with natural draught to burn a given amount of coal per square foot of grate, varying according to the proportions of the boiler and the height of the funnel, etc. The firing could be pushed up to a certain point, but beyond that it was impossible to go; further, when manœuvring, after the boilers had been pushed, if, due to the slowing down of the engines, the demand for steam suddenly ceased, the boilers were then left with very heavy fires upon them, and the dangers attending this state of affairs are considerable.

With forced draught, on the contrary, by accelerating the speed of the fans the power developed can be increased considerably, and in a very short space of time, and further, by reducing the speed of the fans, the power can be dropped equally quickly and without the attendant evils referred to above.

The rates of combustion that can be realised by the employment of forced draught are remarkable. Sir John Durston* says that "with natural draught a much greater combustion than 25 lbs. per square foot of grate surface was rarely achieved; with artificial draught the rate of combustion may be accelerated to any amount." In the marine type of boiler 40 to 50 lbs. may be burnt; in torpedo-boat practice, 70 to 80 lbs., or even higher; in locomotive practice on shore, 120 lbs. and over is not unusual. When forced draught was first introduced on marine type boilers, it was found that it was such an extremely easy and inexpensive method of increasing the power developed, that contractors were tempted to abuse this new method of obtaining increased power, and, consequently, very considerable troubles with leaky tubes and tube plates, "birds-nesting,"† and so forth, were experienced, and a reaction soon set in. The ability of tubulous boilers to stand excessive forced draught without injury was therefore the more appreciated.

18. Advantages of forced draught.—Adaptability of tubulous boilers to forced draught.—The advantages of forced draught may be briefly summarized as follows:—

1. In a properly constructed boiler the power may be increased 30 or 40 per cent., or even more if need be, without injury.

2. With moderate forced draught and properly proportioned grates, an economy in coal consumption can be realised.

3. A poorer and cheaper class of coal can be used.

4. The draught is independent of the weather.

* "Some Notes on the History, Progress, and Recent Practice in Marine Engineering," A. J. Durston. "Transactions, Institution of Naval Architects," 1892.

† Birds-nesting is the name given to the collection of cinders and scoriæ round the mouth of a boiler-tube at the end nearest the fire.

5. The draught is under complete control, and the hot gases can be cooled down to a greater degree (thereby increasing the economy), without affecting the draught, than is the case with a chimney.

6. More perfect combustion can be assured, and smoke prevented.

7. Better air supply and cooler stokehold, a point too often neglected.

Tubulous boilers, on account of their mode of construction, are particularly well adapted for the use of forced draught.

1. They are free to expand.

2. The tube-joints are not exposed to the fire.

3. The heating walls are not so thick nor so likely to become overheated.

19. Forced Draught Results:—

The following results are of interest as illustrating the increase in power of a boiler due to increasing the draught.

RESULTS OF TRIALS OF SIMILAR SHIPS OF BRITISH NAVY (*Trans. N.A.*, 1886)

		I.H.P. Per sq. ft. of grate.	I.H.P. Per ton of boiler.
	NATURAL DRAUGHT		
Open Stokehold	*Inflexible* . . .	10.21	11.22
	Colossus . . .	11.62	12.61
	Phaeton . . .	10.23	12.1
	Mean . .	**10.68**	**11.98**
	FORCED DRAUGHT		
Closed Stokehold	*Howe*	15.54	18.5
	Rodney . . .	16.83	20.1
	Mersey . . .	16.61	21.7
	Scout	16.28	19.3
	Mean . .	**16.31**	**19.9**

CHAPTER III

Large Tube Boilers—Belleville Boiler—Early Type—Later Type—Addition of Economiser — Details of Construction — Results obtained with Belleville Boiler—Babcock and Wilcox Boiler—Land Type—Marine Type—Results obtained—Niclausse Boiler—Dürr Boiler—D'Allest Boiler—Oriolle Boiler—Hornsby Boiler—Stirling Boiler — Heine Boiler — Morrin "Climax" Boiler—Thornycroft-Marshall Boiler.

20. Large-Tube Boilers.—What are generally known as the large-tube boilers, are, roughly speaking, those boilers whose tubes are, say, $2\frac{1}{2}''$ or over, and which are used principally on the larger class of boat, such as cruisers, battleships, etc., and also in land and electric light installations. The tubes are generally straight and inclined to the horizontal. The classification into large-tube and small-tube boilers is not strictly accurate, because, in several instances, some of the tubes of boilers usually classed under the large-tube type, are of no larger diameter than some of the tubes met with in the small-tube type. The large-tube boilers are heavier, more robust, and not so sensitive as the small-tube or express type of boiler. It is not possible in the space of one short lecture to cite all the various types of large-tube boilers in use, but only those which have been more prominently before the public.

21. Belleville Boiler.—There are two types of Belleville boiler at present in use in the British Navy.

The later type (Figs. 94, 95) differs only from the earlier one (Figs. 92, 93), fitted to the *Powerful* and *Terrible*, in having a feed-heater, or "economiser," placed above the boiler

BELLEVILLE BOILER WITHOUT ECONOMISER.

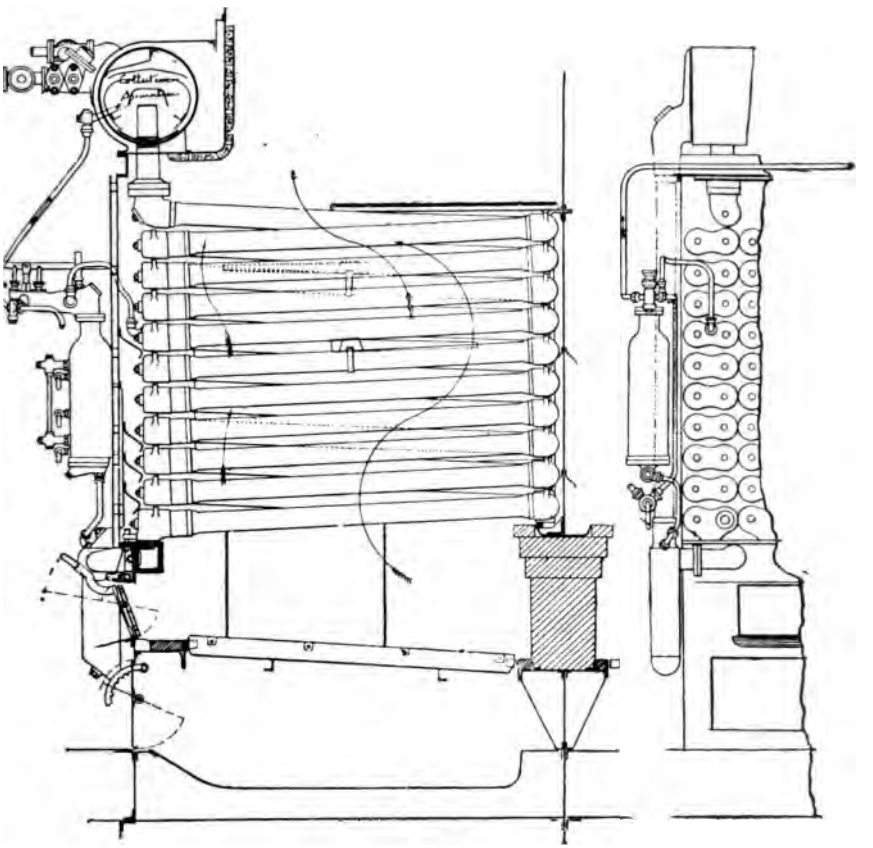


FIG. 92. FIG. 93.

proper, and having the number of rows of tubes in the boiler itself reduced. A description of the later type will, therefore, render a separate description of the earlier unnecessary; as, with the exceptions noted above, and a few necessary and

consequent alterations in minor details, a description of the later type will cover the earlier.

The Belleville boiler (Figs. 94, 95) consists of a series of vertical rows of nearly horizontal tubes *b* placed side by side. Each vertical row is known as an "element." Each element is connected at the top with a common steam reservoir L, and at the bottom with a common horizontal feed-distributor, which supplies the feed-water to each of the different elements (see Fig. 96).

The tubes in each element are inclined in alternate directions, and connected in pairs by horizontal junction boxes B, so that the tubes in each element form one continuous flattened coil or spiral. Water entering one end of an element from the lower feed-collector, has to travel each of the tubes in succession, before it is delivered as steam from the topmost tube.

Hand-holes are fitted opposite the ends of the tubes in all the front junction boxes, the holes being closed by specially constructed doors.

Above the rows of elements forming the boiler proper, is now placed what is known as an "economiser." This consists of a number of elements, precisely similar to those of the generator elements, but composed of smaller tubes b_1. The object of the economiser is to heat the feed-water before it is introduced into the top drum. The feed-water is supplied by the feed-pumps to the automatic feed-regulator A, and passes from thence to the bottom feed-collector G, of the economiser, which is similar to that of the boiler. After traversing the tubes of the economiser, the heated feed-water passes into another collector H (Fig. 95), communicating with the top of the economiser elements, and is then led into the steam drum L; from the steam-drum the feed-water passes down an external down-comer with a settling drum at the bottom, to the

a

BELLEVILLE BOILER.

Side elevation

Section at XX.

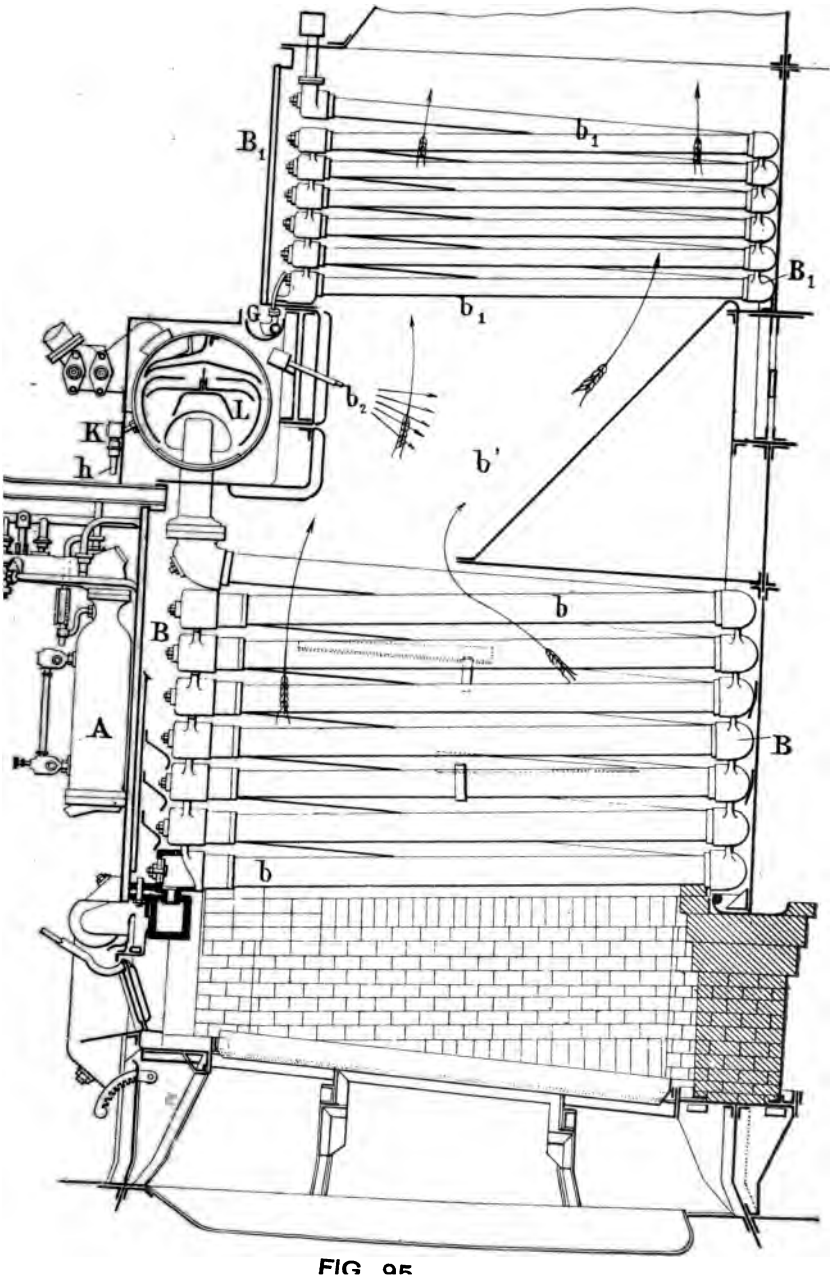


FIG. 95

bottom feed-collector, and from thence into the generating tubes.

"The water is distributed to the different elements by the lower feed-water collector of rectangular section placed above the fire-doors. From this collector the bottom junction boxes take their water through a conical nipple *m*, screwed into the other part of the collector, the whole being held together by a bolt *d* (Fig. 96). The mixture of water and steam, emitted from the upper ends of the elements, passes through short junction boxes into the upper cylindrical reservoir L (Fig. 94). In this reservoir the water is separated from the steam. The steam stop-valve connections are fitted to this reservoir. The principle adopted in the various pieces of apparatus for separating the particles of water from a current of steam appears to have been applied for the first time in the separators of M. Belleville. It consists of giving sharp turns to the current in such a way that the liquid particles are deposited on the concave walls of the passages. The edges of the baffles are notched.

The feed delivery is placed in the separator amidst the steam, and the jet of water, discharged at a very high pressure falls in the form of a highly divided spray.

By spraying the water into the feed-collector, M. Belleville probably intended to bring about a deposition of any salt that might be contained in the feed-water; and, in fact, he reckoned on the possibility of using salt water for make-up when aided by this precipitation and the use of the settling tanks, or separating chambers." *

The use of a separating chamber is the result of considerable experience, and was designed to prevent deposits on the heating surfaces by providing a receptacle in which impurities could be allowed to accumulate without danger

* "Marine Boilers," L. E. Bertin, p. 231.

to the boiler. To facilitate this, the feed is mixed with a small quantity of lime. When raised to boiling point, all the lime in the sea-water, which may have been mixed with the feed, as well as the lime which has been purposely dissolved in the water, separates out in a solid but non-crystallizable form. This deposit, mixing with the particles of oil in the feed-water, forms a kind of mud, which settles to the bottom of the separating chamber or mud drum, owing to the water being comparatively quiet there. Practically no deposit is found in the heating tubes.

The grate is composed of the usual arrangement of fire-bars, and the hot gases ascend vertically across the tubes. Horizontal screens or baffle plates are arranged among the tubes, so as to increase the length of travel of the hot gases, as without these baffles a good deal of heat would pass up the uptake without being utilized. In 1896, when economisers were added, the rows of generating tubes were reduced from 10 to 8. The 1896 type of boiler is shown in Figs. 94, 95. In the boilers of H.M.S. *Diadem*, there are only seven rows of generating tubes of $4\frac{1}{2}''$ diameter in each element; above this is a space b^1 corresponding to the combustion chamber in an ordinary return-tube boiler, and above this again is a nest of tubes, $2\frac{3}{4}''$ in diameter, and seven rows in height, forming the economiser. The furnace air-blowing engines supply jets of air to this space as well as to the furnaces below. The position of the air jets is shown at b_2, Fig. 94.

The use of the economiser is said to have resulted in a saving in coal of over 20 per cent.

In the Belleville boiler, the junctions throughout are made with either bolted or screwed joints, no expanded joints being used. The tubes are screwed into the back junction

boxes, A (Fig. 96), which are made of malleable cast-iron or cast steel, with a slightly differing thread, thus ensuring a tight bearing. The joint with the front junction box B is made by means of a small piece of tube *a*, screwed into the junction box, and a sleeve *b*, which covers the joint. A small back nut *c* prevents the sleeve slipping back when once it has been screwed into position. There is a similar nut *c* at the back end of the tube where it is screwed into the back junction box A.

The replacing of an element of which a tube has given way takes only two hours, but the replacing of a damaged tube in an element when spare or duplicate elements are not to hand,

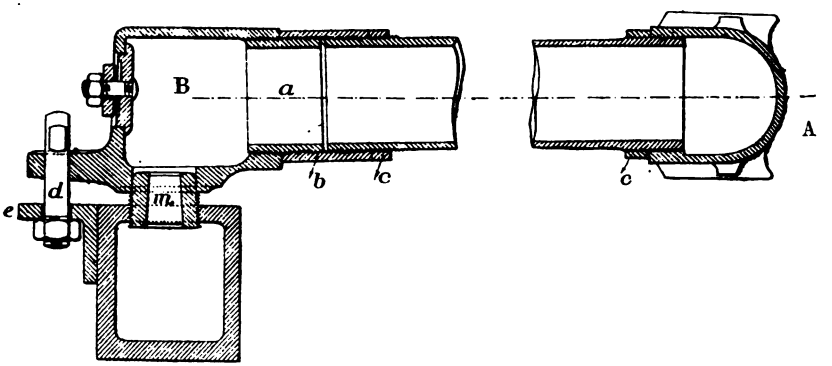


FIG. 96.

takes between four and six hours. This is due to the fact that the back nuts *c* can seldom be unscrewed after being some time in service, and have therefore to be cut with a chisel, and the tubes themselves can not always be unscrewed from the junction boxes.

The tubes are supported one upon the other by small legs, and being simply kept in place by their own weight are therefore free to expand or contract.

The generating tubes are from $3\frac{1}{2}''$ to $4\frac{1}{2}''$ diameter in war-ships, and $5''$ diameter in the French Merchant service. In the *Canopus* class of battleships, and the first-class cruisers

of the *Argonaut* class, the generator tubes are of $4\frac{1}{2}''$ diameter, and the economiser tubes $2\frac{3}{4}''$ diameter. The thickness of the generator tubes is about $\frac{3}{8}''$ for the two or three lower rows, and about $\frac{3}{16}''$ for the others. These details vary slightly in different boilers. Weldless steel tubes are now being used with success.

The following are particulars of the Belleville boilers of H.M.S. *Diadem*. They are thirty in number, twenty of them containing eight generator elements and six economiser elements, six with seven generator elements and six economiser elements, and four with nine generator elements and seven economiser elements. The tubes of the generator elements are of $4\frac{1}{2}''$ diameter, and those of the economiser elements of $2\frac{1}{2}''$ diameter. The following are the principal data for a boiler having eight generator and six economiser elements :—

	sq. ft.
Grate Surface	49
Heating Surface of eight generator elements	995
,, six economiser elements	355
Total Heating Surface	1,350
Ratio $\frac{\text{H.S.}}{\text{G.S.}}$	27.5

		Diadem.	*Argonaut.*	*Hogue.*	*Hermes.*
Number of boilers		30	30	30	18
Heating Surface	economisers sq. ft.	10,950	19,000	—	—
	generators ,,	29,600	28,300	—	—
	Total ,,	40,550	47,300	51,500	24,080
Grate Surface ,,		1,483	1,390	1,650	804
Ratio $\frac{\text{H.S.}}{\text{G.S.}}$		27.34	34.03	31.2	29.95
I.H.P.		17,262	18,894	21,000	10,000
Weight of boilers tons		748	794	915	439
,, per sq. ft. of grate lbs.		1,130	1,279	1,242	1,223
H.S. per I.H.P. sq. ft.		2.35	2.50	2.45	2.4
I.H.P. per ton of boiler		23.08	23.80	22.95	22.78

22. Babcock and Wilcox Boiler, Land Type.—This boiler (Fig. 97) consists of elements composed of straight tubes, placed in an inclined position, and connected together at each end by a vertical header, which communicates with a top steam and water drum.

In the land type the rear header is connected at the bottom to a mud drum or settling tank. The tubes, which are generally 4″ diameter, and lapwelded, are inclined at an angle with the horizontal, and in land work the front end of the tubes is usually the highest. The end connections or headers are in one piece (Fig. 98), and of such a form that the tubes are "staggered," or so placed that each horizontal row comes over the spaces in the previous row. The holes are accurately sized, made slightly taper, and the tubes fixed therein by an expander. The sections thus formed are connected to the top drum, and with the mud drum also, by short tubes expanded into bored holes, doing away with all bolts, and leaving a clear passage-way between the several parts. The openings for cleaning opposite the end of each tube are closed by hand-hole plates, the joints of which are made in the most thorough manner, by milling the surfaces to accurate mechanical contact. They are held in place by wrought-iron forged clamps and bolts, and are tested under hydraulic pressure and made tight without the use of any rubber or other packing. The covers are placed outside, not inside as in ordinary boilers, and the pressure tends to force them off. The plug or dog placed inside the boiler is made in one piece with the bolt which passes through these plates, and is so formed that in the event of the breakage of a bolt and its door falling off, a slight leakage only will result.

The steam and water drum is made of flanged iron or

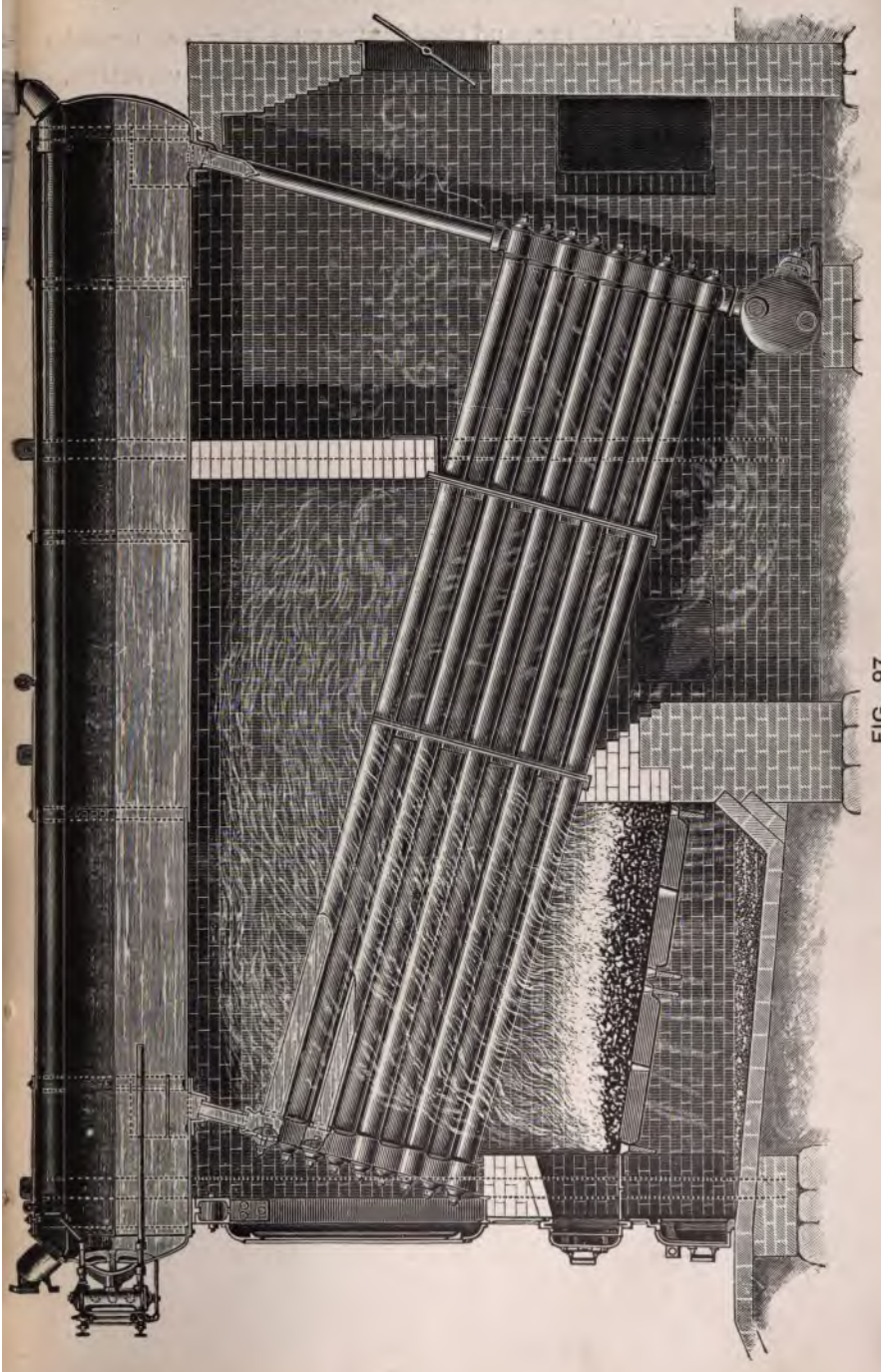


FIG. 97.

steel of extra thickness, and double riveted. The mud drums are of cast-iron, as the best material to withstand corrosion, and are usually about 1″ thick. They are provided with

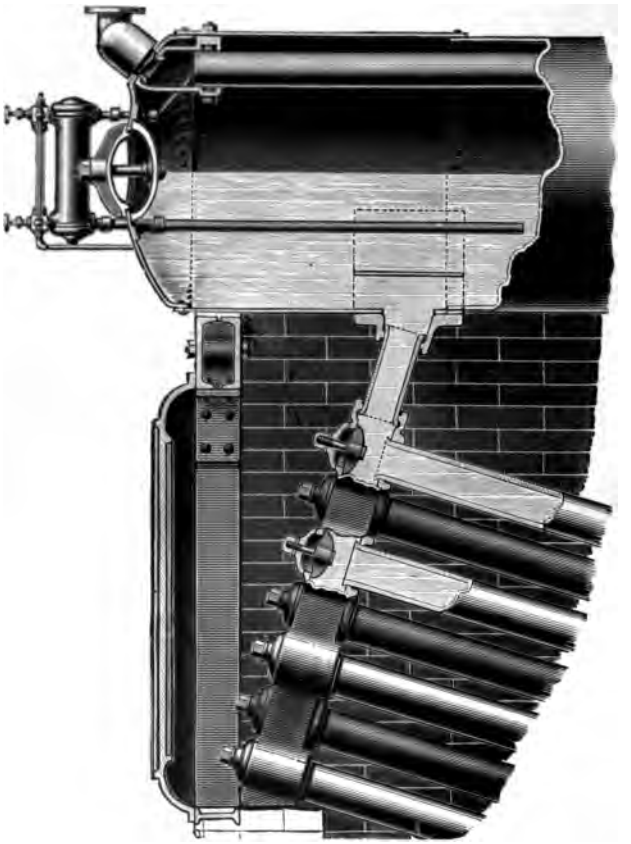


FIG. 98.

means for cleaning. The feed-water is introduced into the mud drum.

The boiler when erected is entirely independent of the surrounding brickwork, being suspended from wrought-iron girders carried on iron columns. This allows of the ex-

pansion of the boiler without damage to the brickwork, which can be repaired or removed if necessary, without disturbing the boiler.

This boiler has been largely employed for land purposes both here and in America, and particularly for Electric Light and Power work. As far as the results obtained by the Babcock and Wilcox boiler are concerned, they have been so numerous that it is rather difficult to select any one series of tests as representative. The mean of thirty tests of the land type of boiler made under varying conditions gives the following results:—

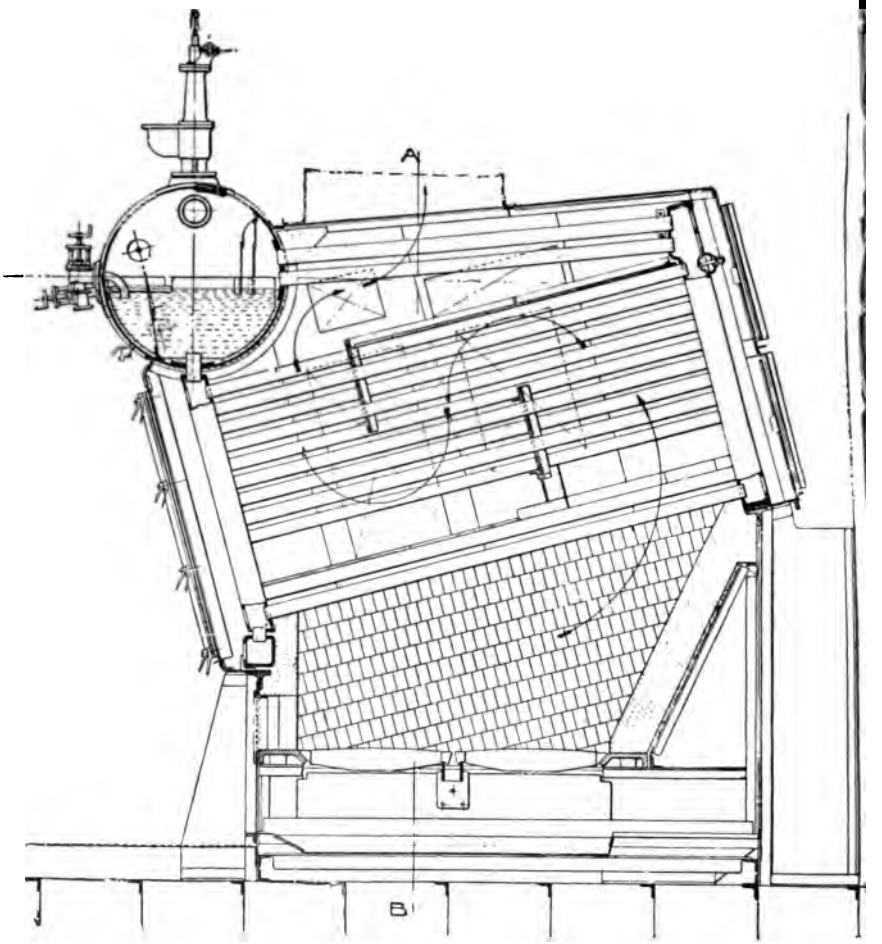
Lbs. of combustible burnt per sq. ft. of G.S. . .	15.03
,, ,, H.S. . .	.32
Water evaporated per lb. of combustible "from and at" 212°	11.38 lbs.

23. Babcock and Wilcox Boiler, Marine Type.—The Company are now developing their marine work, and have fitted over a hundred ships, several of which belong to the United States Navy, and some to our own Navy.

The marine type of Babcock and Wilcox boiler (Figs. 99, 100) differs considerably from the land type. It consists of headers of square section, but curved in a sinuous form, into which are expanded tubes of much smaller diameter than in the land boiler. These headers communicate with the top steam and water drum, which is transverse to the boiler. One main distinction between the land and marine type for naval purposes is that the higher end of the inclined generating tubes is at the back of the boiler and not at the front. The casing is composed of wrought-iron lined with non-conducting composition instead of the brickwork used in the land type. The furnace is

surrounded with refractory brick on all sides. The feed water in the earlier type was introduced either into the top steam and water drum or into a separate feed-drum purifier, where the impurities were deposited before the water

BABCOCK & WILCOX BOILER—MARINE TYPE.



LONGITUDINAL SECTION

FIG. 99.

passed into the boiler, but the use of a separate feed-drum purifier has now been discontinued. H.M.S. *Sheldrake* has

BABCOCK & WILCOX BOILER—MARINE TYPE.

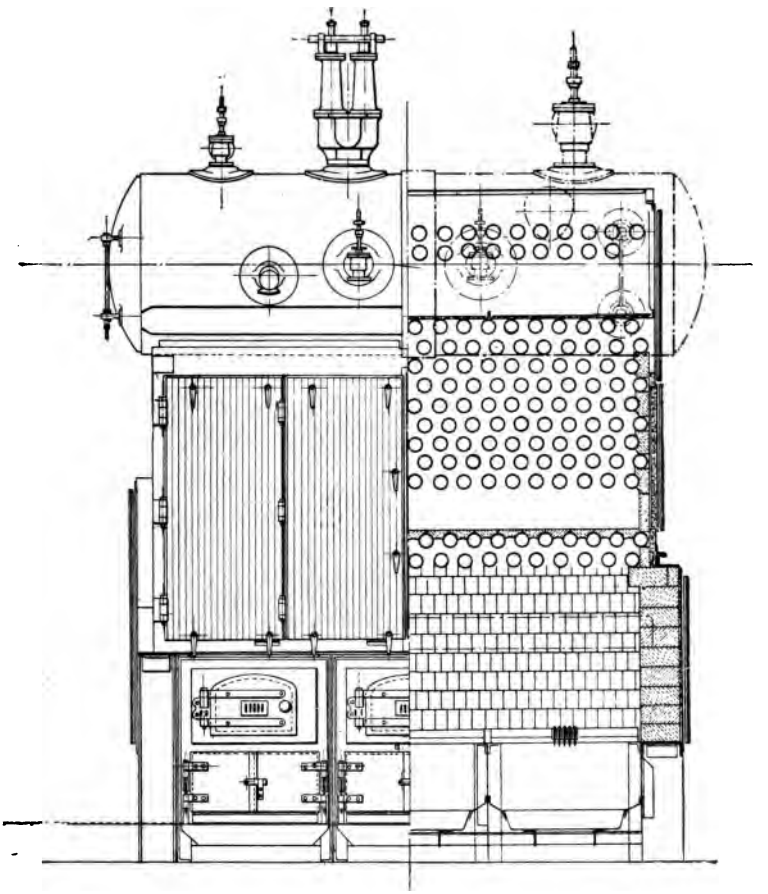


FIG. 100.

been fitted with Babcock and Wilcox boilers of 3,500 H.P., the weight of boilers complete with water being less than

100 tons. The following are some particulars of these boilers.

	Full Power.	Half Power.
Number of boilers	4	4
Total Heating Surface sq. ft.	9,424	9,424
Total Grate Surface ,,	252	252
Ratio $\frac{\text{H.S.}}{\text{G.S.}}$	37.4	37.4
Boiler pressure lbs. per sq. inch	151	152
Air pressure inches of water	0.5	0.2
Temperature of gases at base of funnel Fahr.	550°	550°
Average I.H.P.	4,050	2,642
Weight of boilers tons	96	96
,, per sq. ft. of grate lbs.	853	853
Coal per I.H.P. per hour	1.57	1.43
H.S. per I.H.P. sq. ft.	2.3	3.5
I.H.P. per sq. ft. of grate	16	10.5
I.H.P. per ton of boiler	42.1	27.5

The following are particulars of a land test of one boiler of U.S. *Cincinnati*:*—

Total Heating Surface sq. ft.	2,640
Total Grate Surface ,,	63.25
Ratio $\frac{\text{H.S.}}{\text{G.S.}}$	41.74
Boiler pressure lbs. per sq. inch	209.3
Air pressure inches of water	0.25
Temperature of gases at base of funnel Fahr.	466°
I.H.P. (Contract)	625
H.S. per I.H.P. sq. ft.	4.22
I.H.P. per sq. ft. of grate	9.88
Dry coal per sq. ft. of grate lbs.	20.45
Weight of boiler, empty tons	23.80
Weight of water ,,	4.24
Weight of boiler and water ,,	28.04
Weight per sq. ft. of grate lbs.	992
I.H.P. per ton of Boiler	22.3

* "Journal of American Society of Naval Engineers," vol. xii., No. 4.

24. Niclausse Boiler.—The Niclausse boiler (Fig. 101) consists of a number of vertical headers of malleable iron

NICLAUSSE BOILER.

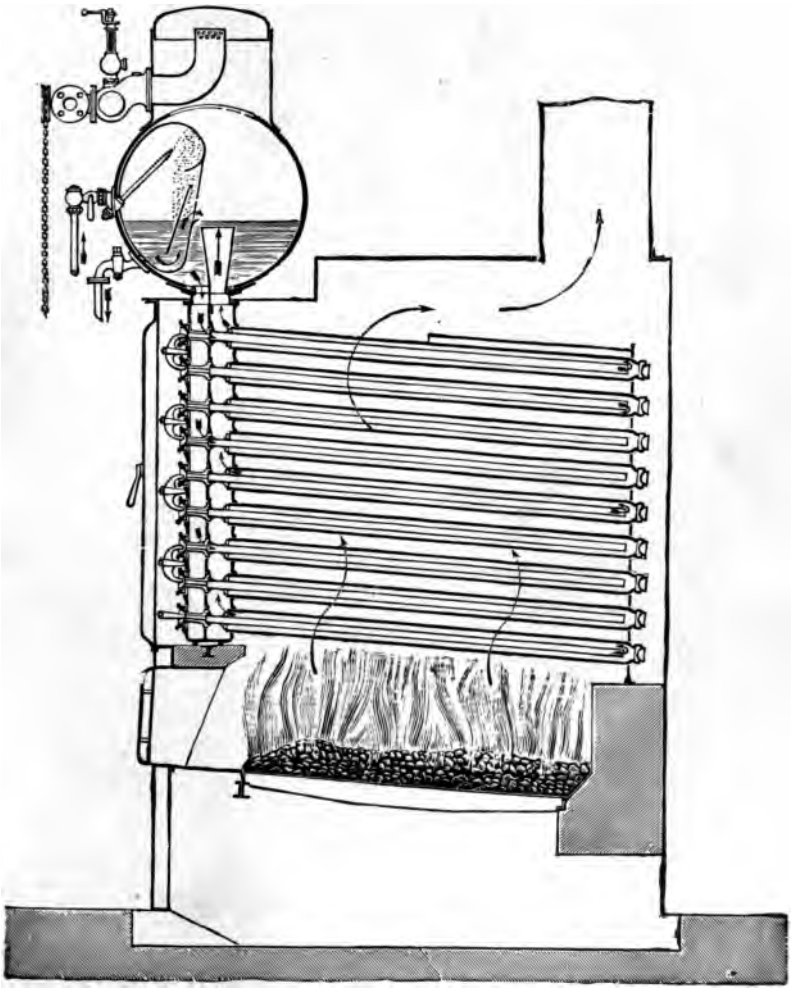


FIG. 101.

placed side by side, each having a number of "Field" tubes fitted to them and slightly inclined from the horizontal. The tops of the headers communicate with the steam and

water drum. These headers are all at the front end of the boiler, none being provided at the back.

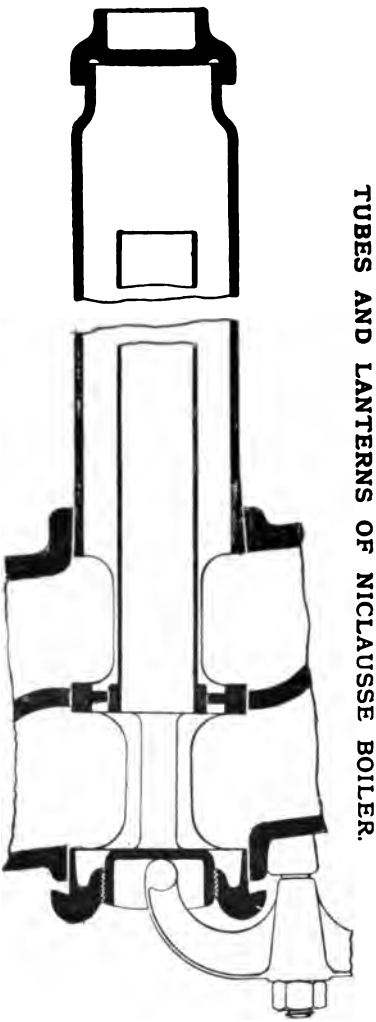


FIG. 102. TUBES AND LANTERNS OF NICLAUSSE BOILER.

The inclined heating-tubes are double, having a concentric inner water tube running down them for nearly their whole length, and the external tubes are closed at the rear end by a screwed cap. The manner in which these tubes are secured to the front header is very ingenious, and readily allows of their removal. The headers are made of malleable cast-iron, and are divided by a vertical diaphragm parallel to the front and rear faces of the header into a front and a rear compartment. The feed-water descends the front compartment of the header, passes through the internal tube of the generating tubes, and the steam generated passes on the outside of the concentric tube, and up the rear compartment of the header into the steam drum.

The method of connecting the tubes to the headers is as follows:—

The external tube (Fig. 102) was until quite recently

permanently connected at one end to a malleable iron casting which is known as a "lantern," but the two are now made in one piece. The end of the tube where it joins the lantern is slightly thickened and turned to a slight taper, and fits into a tapered hole in the rear plate of the header. The middle portion of the lantern, which is cylindrical and of slightly larger diameter, fits into the dividing plate or diaphragm of the header, and the extreme end, which is of larger diameter still, is coned and fits a coned hole in the front plate of the header. This end is screwed internally for the reception of a screwed plug, forming the end of the lantern of the inner tube. Any pressure in the boiler only tends to press the coned surfaces more firmly on their seats in the plates of the header. The object of making each succeeding bearing surface of the lantern of larger diameter than the one before it is to enable the lantern and tube to be drawn out from the front of the boiler. The central cylindrical bearing of the lantern is made an easy fit in the diaphragm dividing the header.

The inner circulating tube is also provided with a lantern of somewhat different form. The end to which the inner tube is attached has a bearing inside the central cylindrical portion of the lantern of the outer tube at the place where it passes through the diaphragm, and the other end, which is slightly coned and also larger, screws into the outer portion of the external lantern, completely closing it. The inner tube is only supported by its lantern at the points where it screws into and closes the outer lantern, and where it passes through the middle cylindrical portion, but as it is exposed to the same pressure internally and externally, it can be made extremely light, the support afforded in the header, provided it is not excessively long, being quite sufficient. The various cones and the holes in the header and diaphragm

are concentric. The outer lantern is fitted with lugs or ears to enable it to be removed from the header. The tubes are kept in place by means of a dog, which bears upon the centre portions of the plugs of two adjacent tubes, and is held there by means of a stud and nut. The external tube is slightly reduced in diameter at its free end, and closed with a cap to facilitate cleaning. At this end it is supported loosely in a steel plate, but the whole tube is free to expand and contract, being only held rigidly at the front end, and consequently the boiler is entirely free from troubles due to expansion of the tubes. The headers are secured to the top drum by a cone connection somewhat similar to the method used in connecting the tubes and headers.

One of these boilers was under trial at the Thames Ditton Works of Messrs Willans & Robinson more or less continuously for over a year, with practically no leak being seen in the 108 tubes of the boiler during the whole of that time, the working pressure being 200 lbs. per square inch. After a year's trial, partly in ordinary working, partly in tests of various kinds, involving frequent withdrawals of tubes, partly in standing idle, the joints were as good as at first.

Several modifications have recently been effected in the construction of the headers and lanterns.

Instead of being of malleable cast-iron as formerly, the headers are now proposed to be made out of a weldless steel tube of square section, the apertures for the insertion of the generating tubes being stamped out by means of special tools. An improvement has also been effected in the tubes and lanterns, the 1900 model (Fig. 103) having the lantern made in one with the tube itself, by milling out portions of the tube, a tube of slightly larger diameter

being employed. By this means, any breaking away of the lantern from the tube is avoided.

In the boilers fitted to the French Ironclad *Suffren*, there are two sets of tubes of different diameters in the same header: six lower tubes of a little over 3″ diameter, and thirty upper tubes of about 1½″ diameter. By this means,

TUBES AND LANTERNS OF NICLAUSSE BOILER, 1900 MODEL.

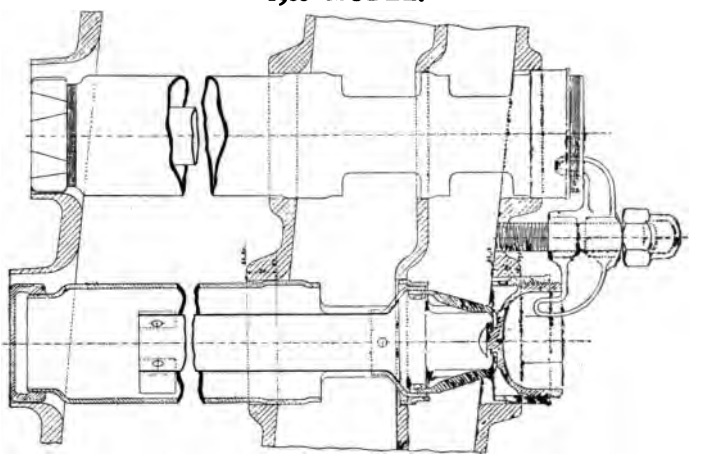


FIG. 103.

a greater heating surface is obtained without increasing the size of the boilers, as in this case the ratio H.S. to G.S. is 37 as against 31 in the boilers of the cruiser *Gueydon*, where only the larger tubes are fitted. There is also a slight saving in weight.*

The Niclausse boiler was fitted to the first-class gunboat *Seagull* for trial, and is now being placed in a new cruiser of 22,000 H.P. It has been very largely used in the French Navy, where it was first fitted on the cruiser *Friant* (Fig. 104), and has also been fitted on several war-ships in the German, Spanish, and Italian Navies, and it is now being fitted

* The estimated I.H.P. per ton of boiler is 46.5 for the *Suffren*.

on the armoured cruisers *Colorado* and *Pennsylvania* in the United States Navy.

Trials have been carried out on this boiler by Professors Kennedy and Unwin in this country, and in America by Mr Jay M. Whitham, at the works of Messrs Cramp of Philadelphia.

BOILER OF *FRIANT*.

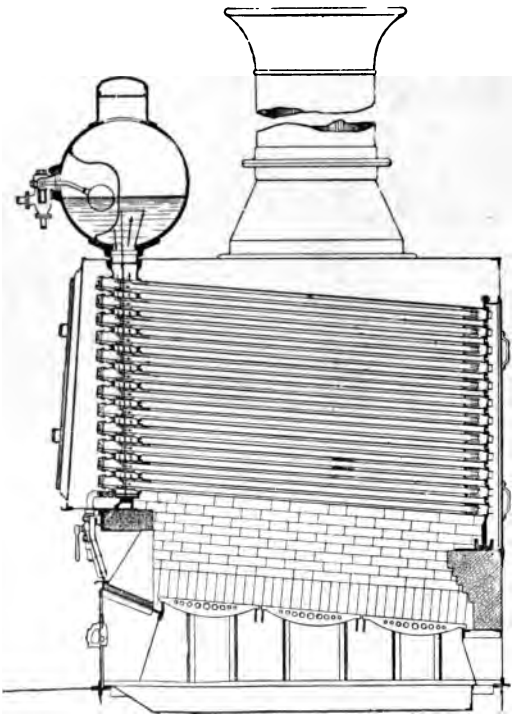


FIG. 104.

25. Dürr Boiler.—The marine type of Dürr boiler (Figs. 105, 106), constructed by Messrs Dürr & Co., of Ratingen in Germany, like the Niclausse, employs an inclined "Field" tube: the chief parts of this boiler are as follows:—

(1) A flat water-space or header, extending over the front of the boiler, divided into two parts by a diaphragm plate,

which is made in portable pieces, each being secured by nuts threaded on the screw stays.

(2) A number of slanting rows of tubes, communicating at

DÜRR BOILER—MARINE TYPE.

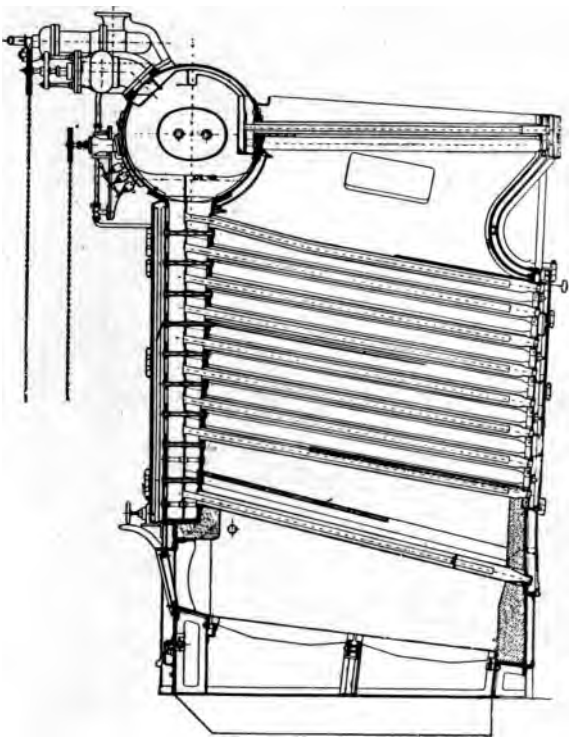


FIG. 105.

their upper ends with this water chamber, and closed at their lower ends, and containing concentric circulating tubes.

(3) A steam receiver placed over the water tubes and connected at the front end to the water chamber.

(4) A nest of superheater or drying tubes placed above the inclined generating tubes.

The water tubes are made at their front ends with rings

welded on and turned conically, the conical portions fitting into the milled holes in the back plate of the water chamber, without requiring any expanding, rolling, or jointing of any kind. As the tubes are placed at an inclination, while the

DÜRR BOILER—MARINE TYPE.

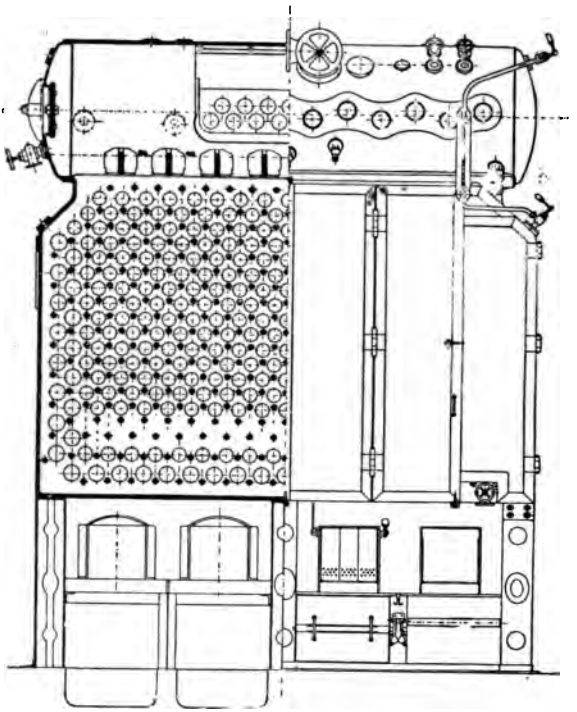


FIG. 106.

water chamber is nearly vertical, the tube ends have to be turned in a special manner to fit at the proper angle. The diameter of the tubes at the rear ends is somewhat reduced; these ends are closed by a conical plug held in place by a bolt and washer. The tube ends are carried on an iron plate forming part of the frame-work of the boiler, protected with bricks, and the tubes are perfectly free to expand or contract.

Circulation is obtained by means of internal concentric tubes fixed to the diaphragm plate, and communicating with the front part of the water chamber. These inner tubes reach nearly to the end of the water tubes.

The water level of the boiler in actual working is about the centre of the steam receiver. The water passes from the receiver down the front part of the water chamber, and then through the inner tubes into the concentric space between the tubes, where part of it is evaporated. The steam and water then find their way out of this space into the rear part of the water chamber, whence they are led into the receivers.

The water tubes at the sides are placed as near each other as possible to prevent loss of heat by radiation. This is effected by bending them alternately to the right and left.

A hole is provided in the front plate opposite each water-tube to enable it to be drawn out or replaced. The holes in the outer plate are closed by hollow caps with conical fitting portions placed from the inside, and like the tube ends these caps fit tight without requiring any rolling or jointing of any kind. The taper ends of the tubes and also of the caps are untooled at the *extreme* ends; these portions therefore are of slightly larger diameter, the collar forming a stop, which is a safeguard against their being blown out from any cause.

The tubes are cleaned on the outside by a steam jet, as in the Niclausse boiler.

Baffle plates are fitted to ensure a proper circulation of the furnace gases among the tubes.

The superheater consists of concentric tubes similar to the water tubes, and the steam circulates through them in the same way, first passing through the inner tube and then through the annular space between the tubes where it is dried or superheated.

The Dürr boiler has been fitted on the German Cruisers

Victoria Luise, *Vineta*, *Prinz Heinrich*, and a new cruiser now building, and on three second-class battleships, and since the issue of the Interim Report by the Boiler Commission appointed by the British Admiralty, arrangements are being made for trying this type of boiler in our own Navy.

The accompanying table gives some particulars of the marine type boiler as fitted to the German cruisers *Vineta* and *Prinz Heinrich*:—

	S.M.S. *Vineta*.	S.M.S. *Prinz Heinrich*.
Number of Boilers	12	14
Working pressure . . lbs. per sq. inch	185	213
Grate Surface (one boiler) . . sq. ft.	49.9	72.66
Heating Surface ,, . . . ,,	2,168	3,059
Ratio $\frac{\text{H.S.}}{\text{G.S.}}$	43.4	42.1
I.H.P.	10,860*	15,390†
I.H.P. per sq. ft. of H.S.	5.01	5.03
Coal per sq. ft. of grate . . . lbs.	41 (about)	34 (about)
Coal per I.H.P. per hour . . . ,,	2.14	—
Air pressure . . . inches of water	1.4	—
Weight of Boiler, dry . . . tons	19.98	28.9
,, water . . . . . ,,	4.92	7.4
Total Weight . . . . . ,,	24.90	36.3
I.H.P. per ton of Boiler	43.61	42.4

* Full power trial. † Contract full power.

The following particulars of tests* made on two Dürr land-type boilers are of interest:—

Heating Surface . . . . sq. ft.	2,727	2,160
Grate ,, ... ,,	56	76
Ratio of $\frac{\text{H.S}}{\text{G.S.}}$	48.7	28.4
Boiler pressure . . lbs. per sq. inch	154	141
Total water per hour . . . . lbs.	5,310	4,060
Evaporation from and at 212°, per lb. of coal ,,	8.2	8.9
Coal per sq. ft. of grate . . . . ,,	13	14.5
Temperature of gases at base of funnel Fahr.	411°	440°

* "Heat Efficiency of Steam Boilers," by Bryan Donkin, 1898.

26. D'Allest Boiler.*—The D'Allest boiler (Figs. 107, 108) which as now made, has been largely used in the French Navy, embodies the improvements in water-tube boilers, patented in France in 1870-71 by Barret and Lagrafel, and in 1888 by Lagrafel and D'Allest. From the first, these boilers were of similar construction to the present D'Allest boiler, the main difference being in the direction of movement of the hot gases. In the present boiler the gases are thoroughly mixed in a combustion chamber before entering the tubes, which was not the case in the earlier forms. The boiler consists of flat stayed water-spaces or headers at the back and front of the boiler, connected by tubes which are expanded into them. The headers are connected to a steam and water drum. The tubes which are inclined to the horizontal, enter the headers at right angles, the headers being inclined to the vertical. The top steam and water drum is also inclined to the horizontal, but not to the same degree as the tubes. The water level is in the steam drum.

The combustion chamber which constitutes the characteristic feature of the D'Allest model of 1888, is situated at the side of the grate. A baffle of bricks resting on the bottom row of tubes, directs the flames into the combustion chamber, from whence they return across the generating tubes. The opening for the escape of the gases from the bank of tubes is placed among the lower rows of tubes, and leads into a smoke-box at the side of the boiler opposite to the combustion chamber. The space occupied by the tubes and the combustion chamber is closed at the top by a second baffle, resting on the highest row of tubes. Below this upper

* For fuller description see "Marine Boilers," by L. E. Bertin, p. 249.

D'ALLEST BOILER.

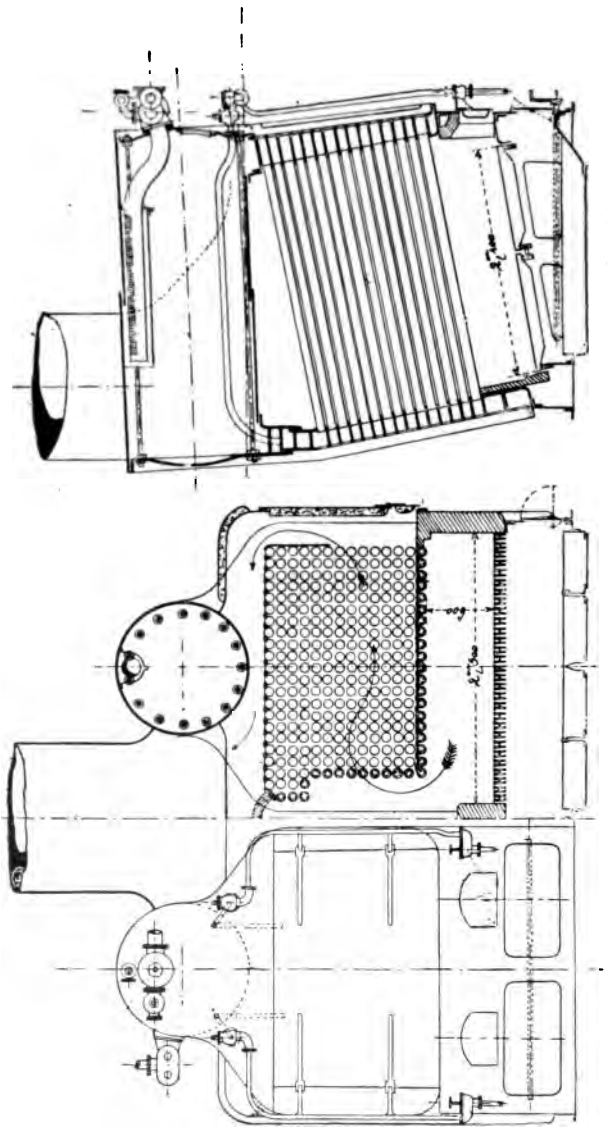


FIG. 108.

FIG. 107.

baffle there are a few rows of tubes in the combustion chamber, so as to prevent it extending upwards to the top of the nest of tubes.

The direction given to the hot gases, though conducive to high efficiency, introduces a source of danger, the gravity of which has been illustrated by the accidents that have occurred on the *Liban* in 1890, on the *Don Pedro*, and finally on the *Jauréguiberry* in 1896. The hottest portion of the furnace gases comes directly into contact with the upper tubes, which are never so effectively cooled by the circulation as the lower ones, and are liable to be filled with accumulations of steam, or even to run short of water, as a result of an accidental lowering of the water level. Since the accident on the *Liban*, the necessity of reducing the height of the combustion chamber has been recognised, and four upper rows of tubes are now carried across it instead of two rows, as formerly.

Each boiler is double, having two furnaces, two sets of tubes, two steam drums and one combustion chamber in the centre common to both furnaces.

Owing to the great length of this combustion chamber, which is of the same length as the grate, its transverse width may be small and directly proportional to the width of the grate.

The tube surface is usually 31.5 times and the total heating surface 33.5 times the grate surface.

Since the first trials of this boiler in the French torpedo gun-boat *Bombe*, Serve tubes have been adopted for the bottom horizontal row, and for the vertical row at the side of the combustion chamber, in order to prevent the bending of the tubes which then took place. A Serve tube is a tube having internal ribs; in a fire-tube boiler it has the advantage of presenting a greater heat-absorbing surface than

ordinary tubes, while the heat-distributing surface remains the same. In water-tube boilers the contrary is the case, and the ribs are of little practical value except for stiffening the tubes.

The tubes of this boiler are of 3″ internal diameter, expanded into the tube plates. Weldless steel tubes have been used exclusively since the opening of a badly welded tube on the *Jauréguiberry*.

The flat plates of the water-spaces are stayed together and the outside ones are provided with hand-holes opposite each tube. The joints for the hand-hole covers are made either with asbestos tightly enclosed between two sheets of lead with an edging of thin copper, or with a copper ring or washer between two lead ones, the three rings forming one complete washer.

The two ends of the top drum are strongly stayed together by horizontal stays arranged in a circle around the inside of the barrel. A curved baffle is fixed inside the drum between the internal steam pipe, and the water level; it acts as a steam separator in much the same way as those in the Belleville boiler, but is much simpler in form. The feed is introduced into the back water-space.

27. Oriolle Boiler.—The Oriolle boiler (Figs. 109, 110) somewhat resembles the D'Allest, consisting of a back and front water-space united by tubes.

The rear water-space is the only one which communicates with the steam receiver, the connection being made by means of a pipe. The tubes are placed directly over the fire, as in the D'Allest boiler, the headers being inclined to the vertical and the tubes entering them at right angles. Two vertical rows of tubes are

placed on each side of the grate to form the side of the furnace. The furnace gases pass immediately in among the lower tubes, which are about 2 ft. 3 in. above the

ORIOLLE BOILER.

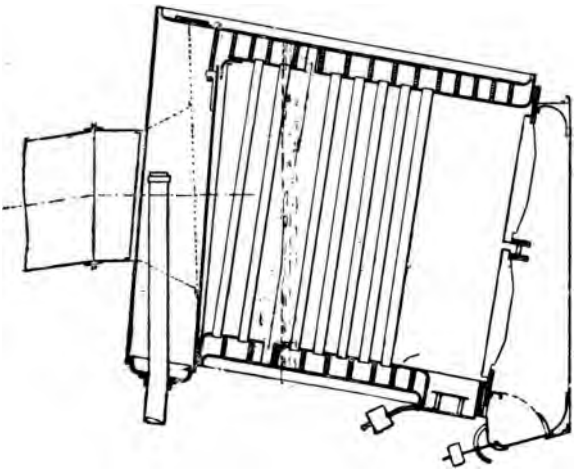


FIG. 110.

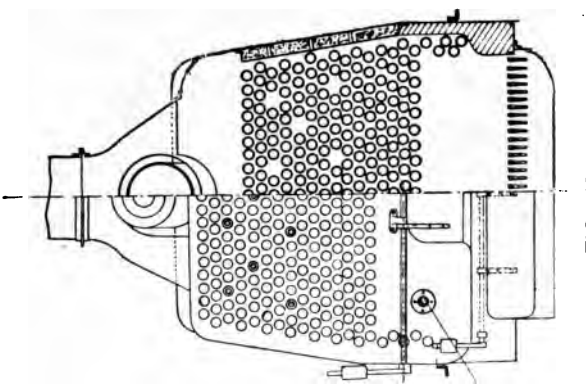


FIG. 109.

grate, without entering a combustion chamber, as in the D'Allest boiler.

The water level is some distance below the upper rows of tubes. The direction of circulation of the water is upwards along the lower rows of tubes, into the front water chamber,

back along the rows of tubes nearest the water level, down the back chamber, then through the tubes again, and so on. The steam liberated in the front header passes by means of the tubes above the water level to the back header, and thence to the steam drum. The tubes used are about 2″ in diameter, and it is stated that so rapid is the circulation that no deposit takes place in them, even if impure water is used. As the water level is some distance below the top, with a total of twenty rows of tubes the four or five upper ones are entirely filled with steam, and the three or four immediately below are, on account of their inclination, partly filled with steam and partly with water.

The tubes were at first expanded into the tube plate, but latterly the Caraman joint (Fig. 111) has been used. In this method of jointing, two rings, one of brass wire and the other of German silver, are pressed into grooves in the thickness of the tube plate, and by the pressure of the expander are forced into the metal of the tube.

CARAMAN JOINT.

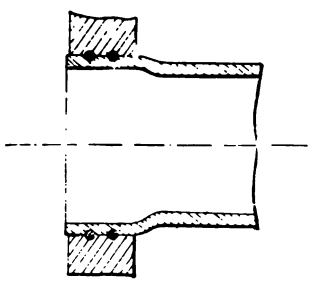


FIG. 111.

No hand-holes for replacing a tube are provided in this boiler, and, consequently, if a new tube had to be inserted, it would be necessary to take the water-chambers to pieces. The flat water-spaces are strongly stayed, some of the stays being tubular so as to allow of the insertion of the steam jets used for cleaning soot from the generating tubes.

The Oriolle boiler has been fitted on several sea-going torpedo boats in the French navy, and about eight first- or second-class torpedo boats. The earlier boilers fitted to the

second-class torpedo boats in 1890 completed three years' service without having undergone repairing. At the end of that time nearly the whole of the steam tubes required replacing, having pitted badly, owing to the use of sea-water as "make-up." The water-tubes were still in good condition.

The boilers of the three first-class torpedo boats launched

HORNSBY BOILER.

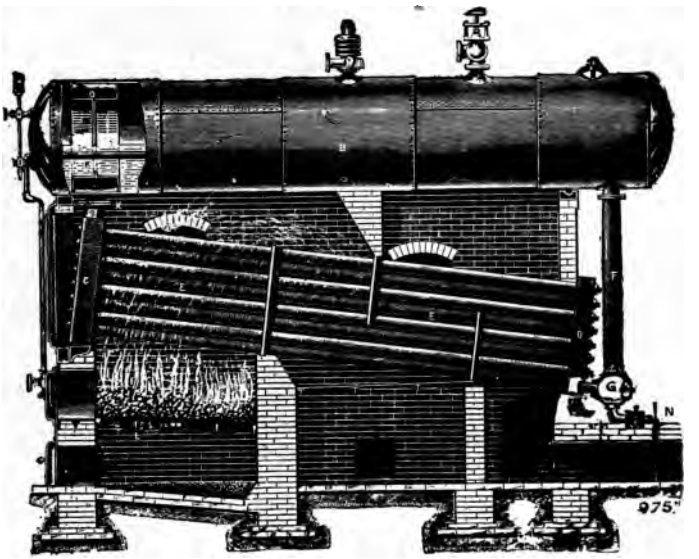


FIG. 112.

in 1892 had 48.4 square feet of grate surface, and the speed obtained slightly exceeded 21 knots while burning 61.4 of coal per square foot of grate. The boilers are very light, being only 573 lbs. per square foot of grate.

28. Hornsby Boiler. — Messrs Hornsby & Sons of Grantham have patented a water-tube boiler (Fig. 112), for

use on land, having flat front and back headers, connected by inclined tubes, and surmounted by a steam and water drum. The headers, formed of flanged mild steel, strongly stayed, are in the shape of a flat rectangular box. There is only one front and one rear header to each steam drum, the headers not being divided into sections, as in many other boilers. The headers are provided with hand-holes, opposite each tube, for cleaning, and are closed by internal oval doors of mild steel, the joints being made with asbestos packing-rings. There is one hand-hole for each tube, and the joints of the covers are made inside the header, so that the steam pressure tends to make them tight. They are pulled into position by an outside dog and nut.

The feed is introduced into the steam and water drum, and passes through outside down-comers, at the rear of the boiler, to a mud drum, from which the rear header takes the water direct, the top of the rear header not being connected to the steam drum. The mud drum is connected to the rear header by short lengths of tube.

A steam and water separator is placed in the front end of the steam drum, immediately above the tubes connecting the front header to the drum. It is an annular chamber formed in the steam drum, perforated by slots on its top side only, and, in passing through this, the steam is separated from the water, and there is very little disturbance of the water-level in the drum.

Fire-brick baffles are placed among the tubes, causing the furnace gases to cross them, transversely, several times on their way to the chimney.

The top drum is supported on iron columns, and the tubes and headers are suspended from it, so that the boiler is free to expand or contract, and the comparatively long length of rear down-comer assists this. The cleaning holes

for the tubes are not exposed to the heat of the furnace gases.

The circulation of the water through the tubes should be fairly rapid, as the hottest part of the furnace gases comes in contact with the hottest part of the water, and the inclination to the horizontal of about 10°, selected by Messrs Hornsby, is that which Mr Watt, in his experiments on the best inclination for tubes, found to be most efficient.* The tubes are straight, and therefore easy to clean, but, from their horizontal position, sediment and soot accumulate more readily on the inside and outside of the tubes, respectively. For economy at high rates of working, the combustion chamber appears to be too small, and the grate somewhat too near the tubes; the mud drum, if the circulation of the water in the bottom tube is very active, should, when working with dirty waters, be of large diameter.

29. Stirling Boiler.—The Stirling boiler (Fig. 113) resembles in form, more nearly than any other of the large-tube boilers, the type most prevalent among the small-tube boilers; that is to say, it consists of a number of upper steam and water drums, connected to lower water drums by curved tubes expanded into the drums at either end. The upper drums are connected together by small tubes above and below the water-level, and the bottom drums are also connected to one another. The number of the drums, both at the top and the bottom, vary according to the type of boiler and the power to be developed. The ends and back and front of the boiler are composed of brickwork, in which suitable doors are provided for cleaning,

* "Transactions of the Institution of Naval Architects," vol. xxxvii., p. 263.

STIRLING BOILER.

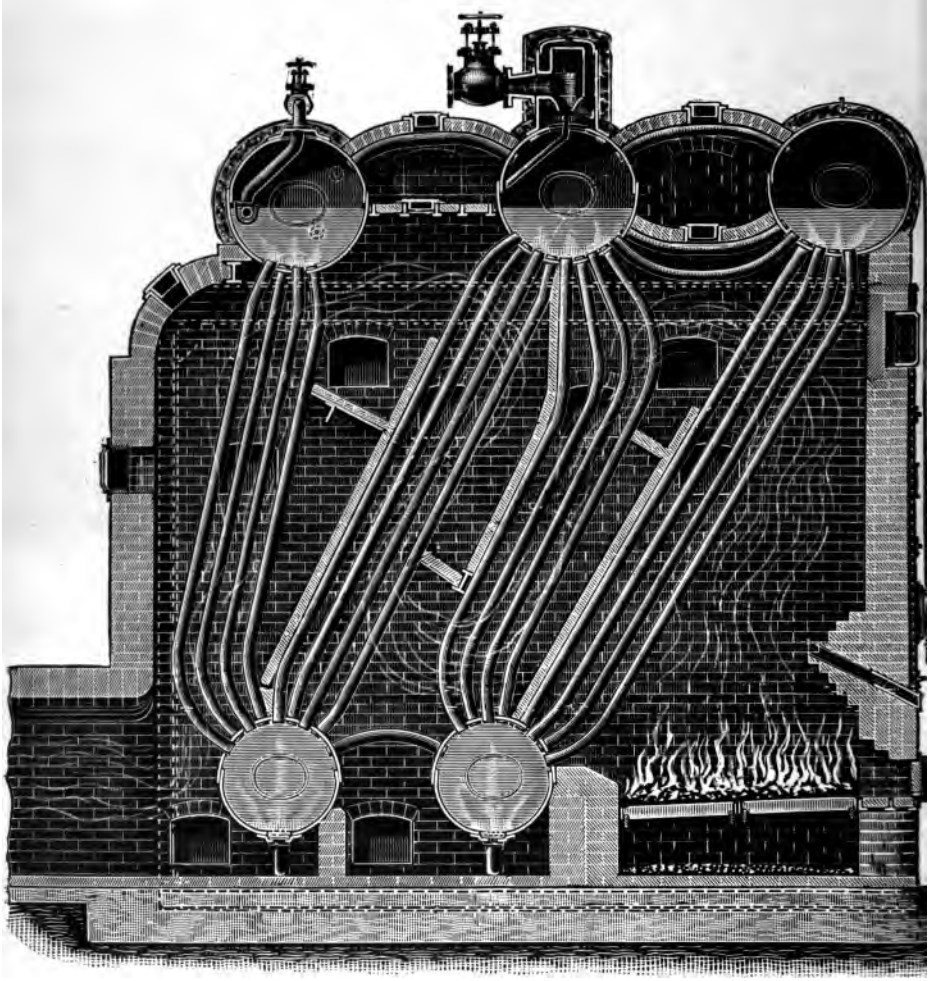


FIG. 113.

etc. The circulation of the water is extremely simple and efficient. Taking the standard type of boiler, with three upper drums and two lower ones, the feed is introduced below the water-level in the backmost top drum. It finds its way down the bank of tubes to the lower water drum, where any solid matter contained in the water is deposited and can be easily blown off. The water then finds its way, by means of the vertical tubes, to the upper drums, or, by means of the tubes connecting the two lower drums, to the front water drum, and thence to the bank of tubes next the fire. The steam is taken off from the top central drum, through an anti-priming pipe situated in a dome over the drum. The course of the gases is easily followed. There is a very large combustion chamber over the furnace, which is an extremely good feature in connection with this boiler, as the gases have ample time to become thoroughly mixed before entering the tubes. By means of suitable baffles, the flames are forced to pass up and down the various banks of tubes until they reach the flue.

The advantages of this type of boiler may be briefly summed up as follows:—

1. The body of the boiler being hung from metal framing, the whole boiler is free to expand without disturbing the brickwork.

2. The distribution of the generating tubes is such that, for a portion of their length, they are transverse to the direction of the gases, and are thus well situated for dividing up the gases and abstracting the heat from them.

3. The tubes approach the vertical, and, consequently, are not likely to become clogged with scale or deposit, besides being better adapted for a rapid circulation.

4. The amount of water contained in the boiler is sufficiently large to overcome any great sensitiveness of the feed.

5. The large combustion chamber ensures ample room for the mixing of the gases, and the presence of refractory brick, on three sides of the furnace, at a high temperature, should conduce to complete combustion. It also enables the boiler to work efficiently with a very low class of fuel.

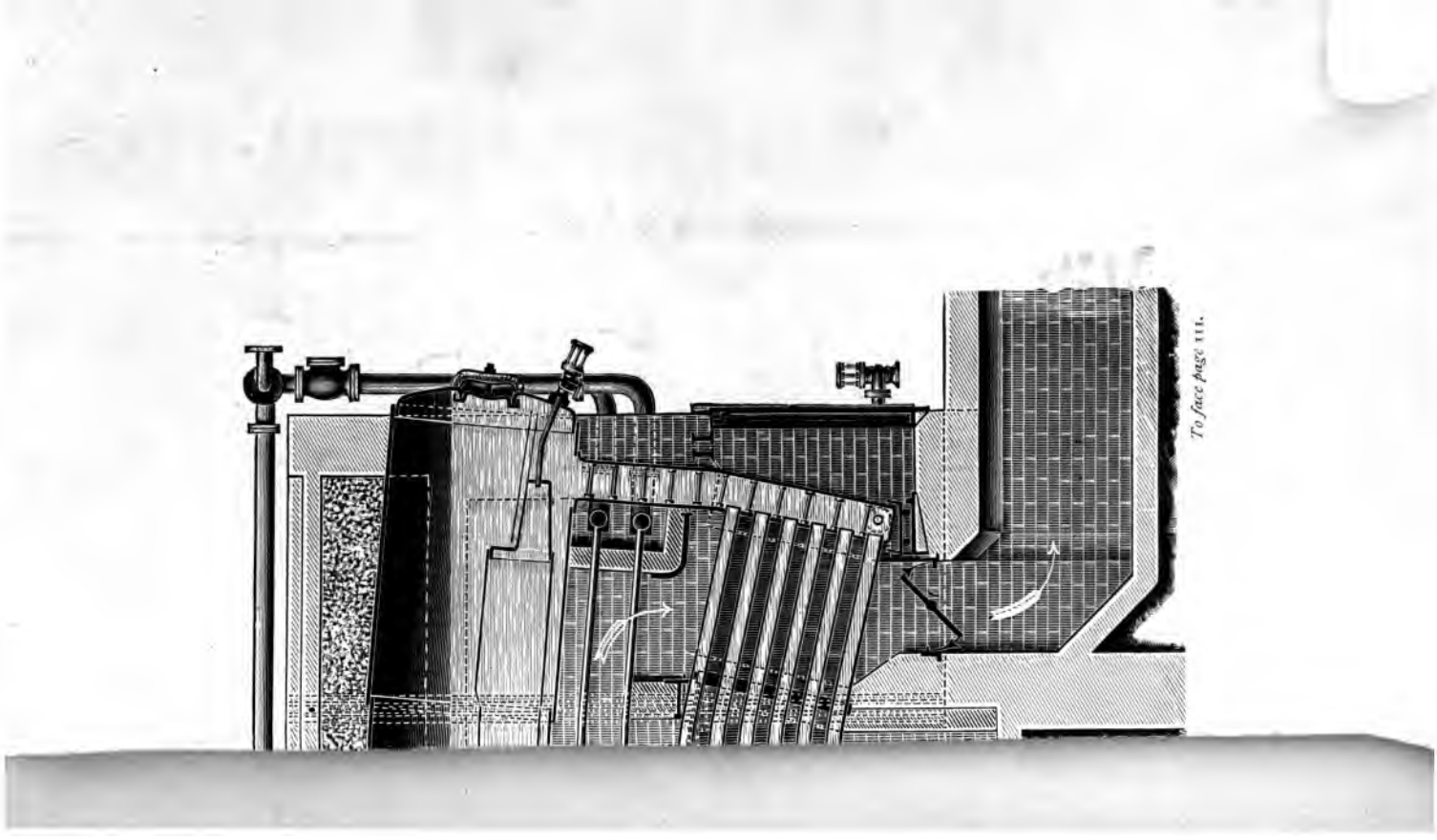
6. The tubes are so arranged that any one tube in the boiler can be replaced without disturbing any other tube.

From tests carried out in America the following results were obtained.

		Full power test.	Max. Efficiency test.
Number of Boilers	3	1	2
Total Grate Surface . . sq. ft.	245.4	48.94	75.94
,, Heating ,, . . . ,,	12,480	2,268	3,418
Ratio $\frac{\text{H.S.}}{\text{G.S.}}$	50.9	46.4	45.01
Average temperature of escaping gases Fahr.	497°	554°	496°
Efficiency of boiler . . . . per cent.	81.34	68.3	82.4
Percentage of moisture in steam . . .	0.58	0.61	0.81
Water evaporated per lb. of dry coal, from and at 212° Fahr. . . . . lbs.	12.44	8.31	9.79
Water evaporated per lb. of combustible, from and at 212° Fahr. . . . . lbs.	13.03	9.57	11.55
Dry Coal per square foot of grate . . ,,	13.3	25.7	14.9
Water evaporated, from and at 212° Fahr., per square foot of H.S. . . . . lbs.	3.25	4.62	3.24

Professor Ewing of Cambridge carried out some tests on one of the boilers erected at the West Brompton Electric Light Station.

Trial A was a natural draught trial to see whether the



To face page 111.

boiler came up to guarantee; Trial B was a short forced draught trial.

	A	B
Total Grate Surface . . . . sq. ft.	43	43
,, Heating ,, ... ,,	1980	1980
Ratio of H.S. to G.S.	46	46
Average temperature of escaping gases Fahr.	455°	590°
Percentage of moisture in steam . . .	0.1	0.15
Water evaporated per lb. of coal (Nixon's Navigation), from and at 212° Fahr. . . lbs.	10.03	10.0
Coal per square foot of grate . . . ,,	22.2	34.3
Water evaporated, from and at 212° Fahr., per square foot of H.S. . . . . lbs.	4.8	7.4

30. Heine Boiler.—The Heine Boiler (Fig. 114) consists of a large upper steam drum, which in some cases is divided into two smaller ones, beneath which are situated a large number of nearly horizontal tubes, connected at either end to flat vertical water-spaces or headers. Opposite the end of each tube there is a hand-hole, the cover being jointed on the inside and held in place from the outside. The whole boiler, both tubes and drum, is slightly inclined, the front being the highest end; the circulation of the water is down the back header, through the inclined tubes, and up the front header. The seating, as usual, is composed entirely of brickwork, the furnace being placed directly under the tubes. Horizontal and vertical baffles are so placed as to force the flames to circulate among the tubes before passing to the chimney. Arrangements are also made for the introduction of auxiliary air to ensure complete combustion. The particular feature of the boiler appears to be the introduction of the feed-water into a large reservoir contained in the upper drum, the blow-off being fitted to the lower and opposite end of the reservoir

to that from which the feed enters. The internal reservoir is open for a short distance on its top side; thus the feed-water is brought up to the full temperature of the steam, and deposits its impurities before mixing with the other water in the boiler. The impurities are thrown down to the bottom of the internal feed-reservoir, and can be blown off by means of the blow-off cock.

The following are some particulars of evaporation trials made on two Heine boilers.

Heating Surface . . . . . sq. ft.	710*	1,407†
Grate Surface . . . . . ,,.	10.75	27
Ratio $\frac{\text{H.S.}}{\text{G.S.}}$	66	52
Boiler pressure . . lbs. per sq. inch	67	123.3
Total water per hour . . . lbs.	1,320	7,799
Evaporation from and at 212° Fahr. per lb. of coal . . . . . lbs.	7.9	10.74
Coal per sq. ft. of G.S. . . . . ,,	18.5	31.7
Temperature of gases at base of funnel Fahr.	490°	644°

* "Heat Efficiency of Steam Boilers," by Bryan Donkin, London, 1898.
† "Boilers and Furnaces," by Barr, Philadelphia, 1899.

31. Morrin "Climax" Boiler.—This boiler (Fig. 115) was first introduced in the United States, and consists briefly of a central vertical drum, into which are expanded large numbers of loop-like tubes, one end being a good deal higher than the other to assist the circulation. The tubes vary in diameter from $1\frac{1}{2}''$ to $3''$.

The central drum is welded and has no vertical riveted joint. It runs the whole length of the boiler, the bottom part below the grate being used as a settling drum. At the top of the drum there are baffle-plates which cause the steam generated to circulate through the upper rows of tubes, and so become superheated. The water-level of the boiler is

MORRIN BOILER.

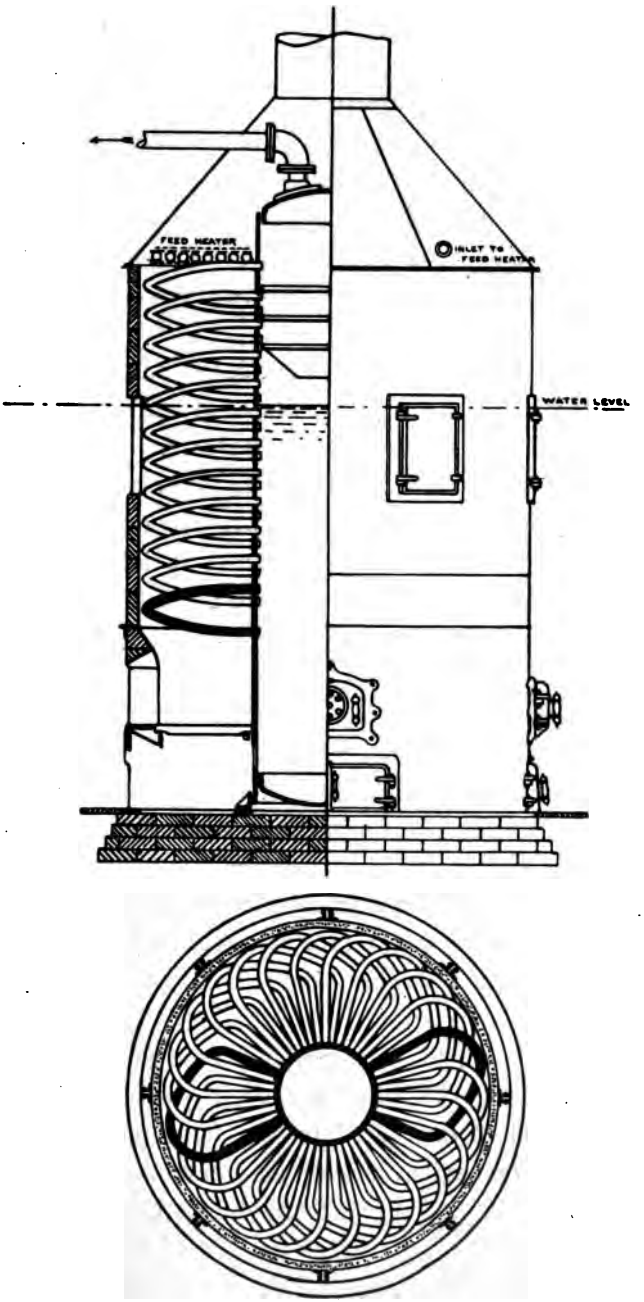


FIG. 115.

about two-thirds up the central drum. At the top there is a long, flat coil through which the feed-water circulates and is heated on its way to the boiler.

The casing is cylindrical and composed of brick with outside metal casing. It is easily removable, and therefore the tubes are readily accessible.

The good points of the boiler are briefly as follows :—

1. Very small floor-space occupied. A boiler of 1000 H.P. is stated to occupy a floor-space of only 17 ft. diameter.
2. Steam is superheated to about 80° Fahr.
3. Few joints—no screwed joints, or ground joints.
4. Elasticity—quickness of raising steam.
5. All parts are small except the central drum.
6. Accessibility—facility for repairs.
7. Tubes cross the course of the gases at right angles.

The disadvantages may be summed up as follows :—

1. Tubes cannot be cleaned (though circulation appears to be good).
2. Circular fire-grate is objectionable.

32. Thornycroft-Marshall Boiler.—Messrs Thornycroft & Co., of Chiswick, in conjunction with Mr Marshall of Hawthorn, Leslie & Co., Ltd., of Newcastle, have recently brought out a form of large tube-boiler for marine work. It is made in two forms (Figs. 116, 117, 118, 119), the sectional form being due to Mr Marshall, the non-sectional to Messrs Thornycroft.

As will be seen, the non-sectional type (Figs. 118, 119) consists of a number of inclined and slightly curved generating tubes, expanded at one end into the front plate of a rear water-chamber or header, and at the front of the boiler the tubes are united in pairs by junction boxes closed by doors.

THORNYCROFT-MARSHALL BOILER—SECTIONAL TYPE.

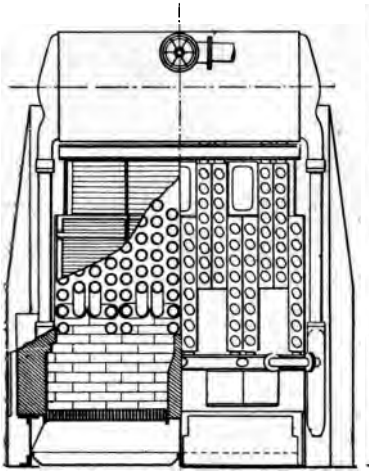


FIG. 116.

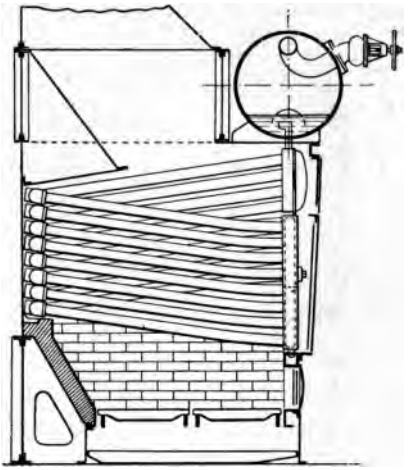


FIG. 117.

THORNYCROFT-MARSHALL BOILER—NON-SECTIONAL TYPE.

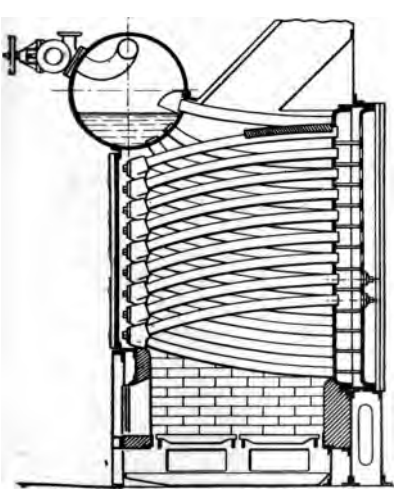


FIG. 118.

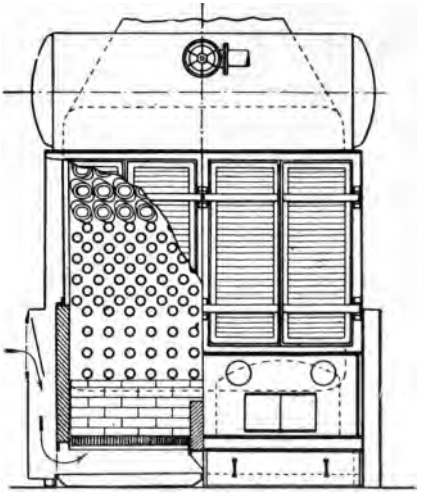


FIG. 119.

By this arrangement only one door at the front end is required for cleaning two tubes. An opening, also closed by a door, is made in the back plate of the water-chamber opposite each tube, for the purpose of inspection and cleaning.

The feed is introduced into the top-water drum, and from thence flows by means of two rows of tubes into the back-water space. The water flows into the lower tube of every pair, and the steam and water issue from the upper tube into the back-water space, from whence the steam passes into the steam and water drum by means of tubes which enter the boiler-drum somewhere about the water-line. Any water carried over by the steam is caught by the umbrella-baffle shown in the figure. The hot gases cross the tubes nearly at right angles, and, as their arrangement necessitates a lesser number of tubes in the lower part of the boiler, combustion is more nearly complete before the hot gases are cooled down by contact with the more closely spaced tubes.

In the sectional type of boiler (Figs. 116, 117) the rear ends of the tubes are expanded into separate cast headers instead of into a flat water-space. This has the advantage that any section or element can be completely removed and replaced by another. In this boiler, owing to the arrangement of the sections, as shown in Fig. 116, a number of combustion-chambers are formed over the furnace, thus allowing for the more complete mixing of the gases. A common feed-distributing pipe supplies the lower ends of the elements with water, and external down-comers are provided to return the water from the upper drum to the feed-distributing pipe.

The following are particulars of one of several eight-

hour evaporation trials, made on the non-sectional boiler in March 1901.

Heating Surface	sq. ft.	1200
Grate Surface	,,	32.5
Ratio $\frac{\text{H.S.}}{\text{G.S.}}$		37
Weight of boiler	tons	14.25
,, water	,,	3.00
,, boiler complete with water	,,	17.25
Weight of boiler per square foot of grate	lbs.	1189
Boiler pressure, lbs., per square inch		211
Evaporation, from and at 212° Fahr. per lb. of coal	lbs.	10.318
Coal, per hour, per square foot of grate	,,	20
Temperature of gases at base of funnel	Fahr.	557°

CHAPTER IV

Small-Tube Boilers—Thornycroft Boiler—*Speedy* Type—*Daring* Type—Du Temple Boiler—Normand Boiler—Normand-Sigaudy Boiler—Mosher Boiler—Reed Boiler—White Boiler—Ward Coil Boiler—Ward Launch Boiler—Mumford Boiler—Fleming & Ferguson Boiler—Blechynden Boiler—White-Forster Boiler—Yarrow Boiler.

33. Small-Tube boilers.—Small-tube boilers or "express" boilers, as they are often called, are, generally speaking, those boilers which, from their greater lightness, are used on torpedo boats and similar classes of vessels, where lightness and high speed are essential. They are far more sensitive than the large-tube boilers, contain less water, and the diameter of the generating tubes ranges from 1″ to $1\frac{3}{4}$″, or thereabouts. They usually consist of a large upper steam and water drum, connected by generating tubes of various forms, to two or more water drums below. Although there are many different types of these boilers in use, more or less resembling one another, time precludes us from describing many of them which, though interesting, in themselves, have not, so far, come into general use.

The employment of small-tube boilers is almost entirely restricted to Marine work, and more especially to Naval purposes.

34. Thornycroft Boiler.—The Thornycroft boiler has been fitted to a very large number of boats in our own and foreign Navies, and Mr Thornycroft was the first in this country to bring the small-tube boilers to a successful

lower half of the drum, and permit of the steam passing to the internal steam-pipe.

Objections have been raised to the curved tubes above the water-level, on the ground that they are only filled with an emulsion of steam and water, though exposed to the hot gases; this, however, is not so serious a defect as the fact that, when out of commission, boilers are often filled up with an alkaline solution, to prevent oxidation, and that then these curved tubes form air-pockets, which cannot be filled. In consequence of this defect, Messrs Thornycroft have altered the form of their tubes, and the position in which they enter the upper drum, so as to avoid the air-pockets, and in their latest design (Fig. 122) this has necessitated the greater proportion of the tubes delivering below the water-level.

The material of which the boiler is composed is now entirely steel, the small generating tubes being galvanized, though it is a moot point as to whether this galvanizing has any really great beneficial effect, and in some cases various contractors are dispensing with it, and increasing the thickness of their tubes; but where galvanizing is still practised, electro-depositing has been substituted for pickling and dipping. In the early days of the introduction of tubulous boilers, a good many experiments were made by Thornycroft, Yarrow and Normand, to find out the most suitable material for the tubes. Copper was tried, as it was thought that it would prove a more satisfactory material than steel, not being subject to pitting, and it is also six times as good a conductor of heat. It was, however, ultimately discarded, no extra evaporative efficiency being detected over the steel. Brass tubes were also tried, but these had to be discarded, as they proved too brittle.

In 1892 Mr Thornycroft brought out a modified form of his boiler, known as the *Daring* type (Fig. 121), as it was first

used on H.M.S. *Daring*. This type has now been fitted on a large number of boats, ranging from destroyers upwards. The *Daring* type of boiler has a large central upper steam and water drum, and a central bottom water drum, with two water drums at each side, the furnaces being placed between the water drums; that is to say, there are two furnaces to each boiler, instead of one, as in the *Speedy* type. In place of using the umbrella baffle of the *Speedy* type, Messrs Thornycroft have used a vertical baffle, composed of V-shaped slats, placed one behind the other, and staggered. These arrest the water, but allow the steam to pass. The latest design for the *Daring* type of boiler is shown in Fig. 122.

THORNYCROFT BOILER—*DARING* TYPE.

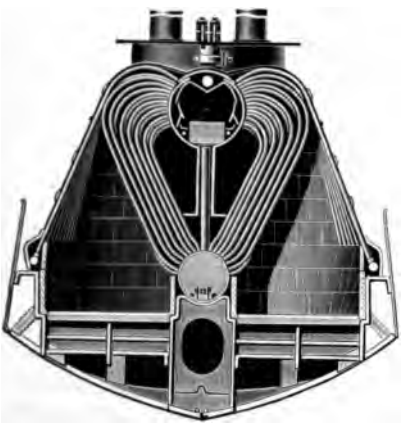


FIG. 121.

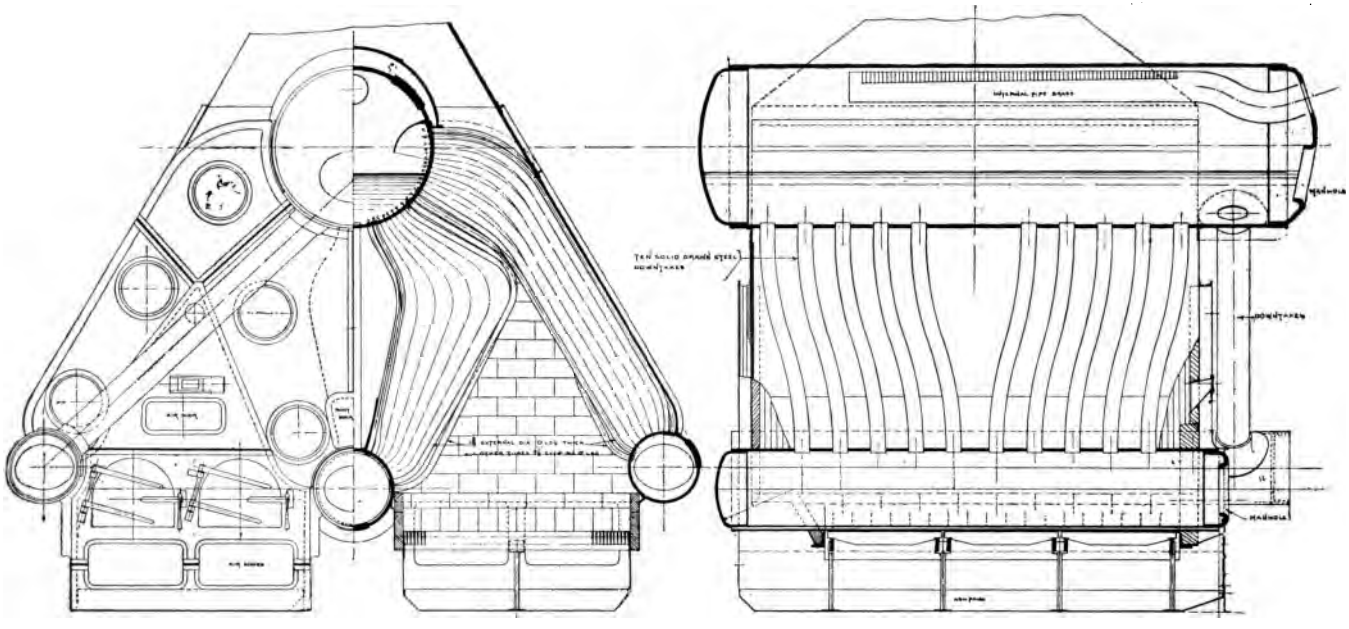
The advantages of these boilers are :—

(1) That they can be made in large units, thus reducing the number of boilers in the ship.

(2) They lend themselves more easily to arrangement in large vessels.

One of the main drawbacks to the Thornycroft boiler, in common with the Normand and many other boilers, is that it is impossible to remove the majority of the tubes, without disturbing those in the immediate vicinity. This difficulty is, however, more apparent than real; the tubes are small and thin, and it is not so difficult to remove and replace them, as would have been the case had they been of similar diameter and thickness to those used in large-tube

THORNYCROFT BOILER—IMPROVED *DARING* TYPE.



	PER BOILER	TOTAL FOR THE FOUR BOILERS
TOTAL TUBE SURFACE	3600 ☐	14400 ☐
GRATE AREA	63 ☐	252 ☐
WORKING PRESSURE	230 lbs per ☐"	
TEST PRESSURE	320 lbs per ☐"	

SPECIFIED I.H.P. 7000

FIG. 122.

boilers. The curved form of the tubes absolutely precludes any internal inspection or passing of a cleaning tool through the tubes, except it be in form of a chain or wire rope. Soot is cleaned from the outside of the tubes by a steam jet in the ordinary way.

The circulation in most of the tubes is very rapid, and therefore an accumulation of scale is not so likely to occur. Due to the form of his tubes, Mr Thornycroft is able to give his boiler a very large ratio of H.S. to G.S., being as high in some instances as 75 to 1, but it must be borne in mind that this ratio, or amount of heating surface, cannot be accepted as a measure of the efficiency of any given boiler, as the relative value of a square foot of heating surface may vary enormously. For instance, the heating surface of the tubes next the furnace does far and away more than its share of evaporation (p. 68), whereas the heating surface, situated at the top and bottom of the outer rows of tubes more remote from the fire, can do very little work, if any, the gases not being brought properly in contact with them. The following are the results obtained on H.M.S. *Speedy* and *Foam*.

	Speedy.	*Foam.*
Number of Boilers	8	3
Total Grate Surface . . . sq. ft.	204	196
,, Heating Surface . . . ,,	17,700*	12,060
Ratio $\frac{\text{H.S.}}{\text{G.S.}}$	86.7	61.5
Total weight of boilers . . . . tons	87.45*	55.2
,, per sq. ft. of grate . lbs.	960	631
Total I.H.P.	4,704	5,846
,, per sq. ft. of grate . . .	23.1	29.8
,, per ton of boiler	53.8	106
Coal per I.H.P. per hour . . . lbs.	—	2.2
,, sq. ft. of grate . . . . ,,	—	65.7

* Minutes of Proceedings, Inst.C.E., vol. cxix., p. 29.

35. Du Temple Boiler.—The du Temple boiler was one of the first, if not the first, of what we have called the "small-tube" boilers, to be developed on anything like a practical

DU TEMPLE BOILER.

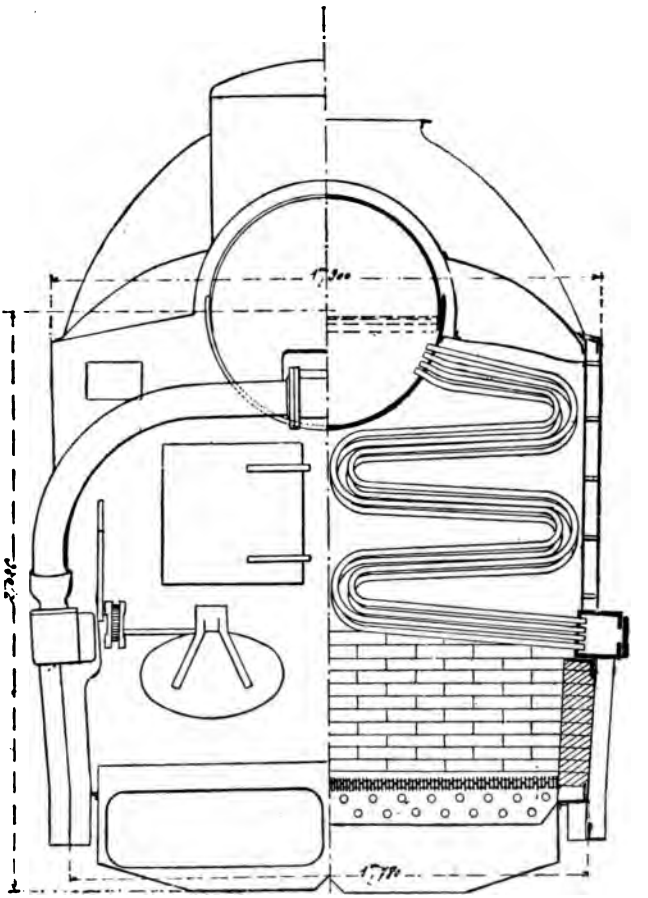


FIG. 123.

scale. Curiously enough, its first application was intended for a flying machine, and in some respects, Hiram Maxim followed the design of the first du Temple boiler for his flying machine. Du Temple's flying machine was a failure,

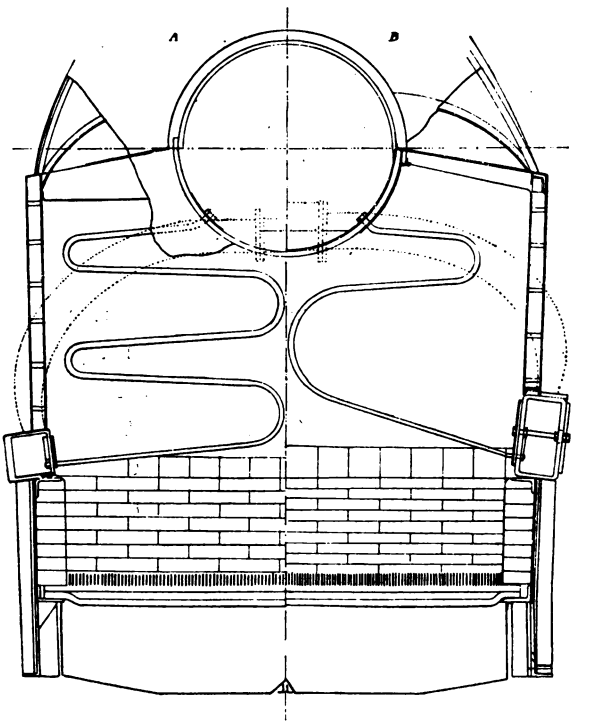
but in 1878 some launches, and afterwards some torpedo boats were fitted with his boilers, and, certainly as far as the French Navy—which was the first to use small-tube boilers—is concerned, Commander du Temple must be given the credit for introducing the first "small-tube" boiler, though it was not until later, when M. Normand improved the du Temple boiler, that it can in any way be said to have been a really practical success.

One of the earliest forms of du Temple boiler (Fig. 123), consisted roughly of one large central upper drum and two small side bottom drums, connected by small generating tubes. These tubes were very long, of small diameter, and bent backwards and forwards several times over the furnace.

The large upper central drum acted as a steam and water reservoir, the water level being about the centre of the drum. The generating tubes discharged *below* the water-level, and the steam was taken from a dome fitted on top of the central drum, by means of an internal steam pipe, this internal pipe being bent upwards into the dome to prevent as far as possible any water being carried over with the steam. Large external down-comers were provided to return the water from the top central drum to the lower drums. The small generating tubes were at first very thin and about 0.4″ diameter, and were expanded into the central drum and the square cast-iron boxes which formed the bottom side reservoirs. Between the bottom and top reservoirs, the small-tubes were bent backward and forward no less than five times. Hand-holes were provided on the sides of the cast-iron boxes, for getting at the lower ends of the small-tubes, and the larger upper central drum was of sufficient diameter to permit of a man working in the drum.

As will be evident, the circulation of the water was down the large outside down-comers and up through the small generating tubes.

The grate was situated between the two small lower



A. Early form of the Du Temple boiler. **FIG. 124.** B. Du Temple boiler as modified by M. Normand.

reservoirs, and the gases, after passing in among the small generating tubes, passed out through the funnel situated over the centre of the boiler. It was not realized at this early date that pure feed-water is an absolute necessity for this class of express boiler, and owing to the smallness of the tubes, trouble was soon experienced by some of the tubes

giving out. Due to the fact that the tubes were kept too close to the fire bars, and that consequently the combustion chamber was too small, at high rates of working combustion was incomplete, and excessive flaming at the funnel occurred.

Commander du Temple died, and his boiler was improved and modified by other engineers, notably M. Normand of Havre. One of the principal improvements was that the number of folds or bends was gradually decreased (Fig. 124), and the diameter of the generating tubes increased. At one time the upper part of the tubes was made of a greater diameter than the lower part of the tubes, to facilitate the escape of steam. The idea of using two diameters, though it may have had some theoretical advantages, practically proved a failure, and the tubes are now made of uniform diameter. In 1889 the tubes were 0.67″ external diameter; they are now 1.38. Another improvement was that the square cast-iron bottom reservoirs were replaced by cylindrical drums, and a baffle was added underneath the funnel, to force the flames to spread more evenly over the tubes at either end of the boiler (Fig. 126). In 1896 M. Guyot, at Cherbourg, in common with M. Normand, appears to have adopted over a portion of the grate what is known as a "tube wall," placing the tubes so close together that they practically touched each other, and thus preventing any flame from passing between them; the gases were thus forced to take a horizontal direction and return through the boiler to the front end. M. Guyot makes the joints of the tubes with the upper drum by means of a steel cone and nut on the inside of the drum. This arrangement facilitates removing the tubes, but the tubes naturally have to be spaced further apart than when simply expanded into the drum. This design of

DU TEMPLE-NORMAND BOILER.

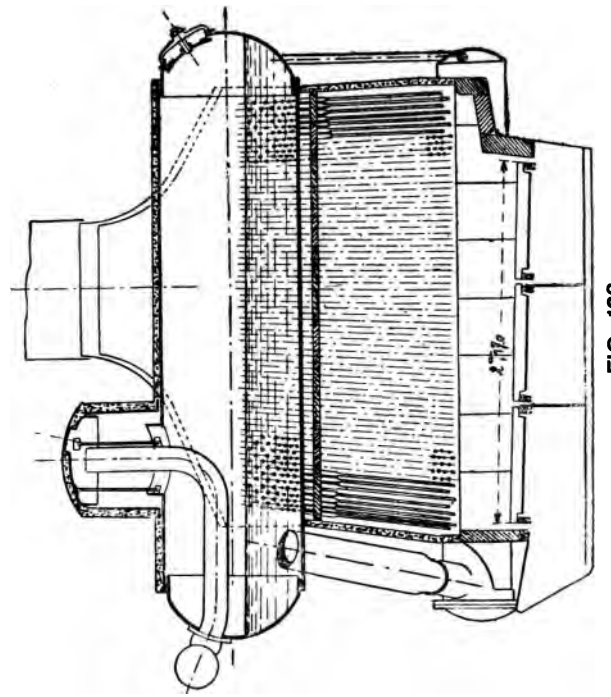


FIG. 126.

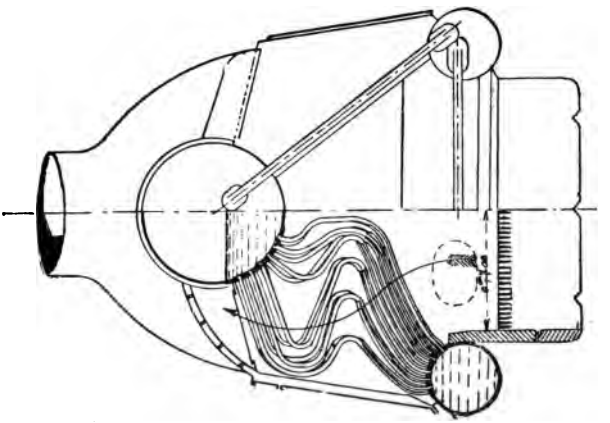


FIG. 125.

boiler is known as the du Temple-Guyot boiler. One of the largest ships in the French Navy, the *Jeanne d'Arc*, a boat of 28,000 H.P., is being fitted with this class of "small-tube" boiler. The du Temple boiler has been fitted in our own Navy on board H.M.S. *Spanker*, a boat of 3,500 H.P.

36. Normand Boiler.—M. Normand's boiler (Figs. 127, 128) is practically the outcome of his simplification of the du Temple boiler, and many of his improvements have been adopted by the du Temple firm. The principal ones, as has been stated, being (1) the suppression of the large number of bends in the generating tubes; and (2) giving the gases a horizontal direction through the boiler instead of a vertical one—the funnel being placed either at the back or front of the boiler, whichever is best suited to the vessel. The boiler is said to be of either the "direct-flame" type or the "return-flame" type, according as the funnel is at the back or front of the boiler.

The two inner rows of generating tubes next the furnace and the two outer rows next the casing are made, for a portion of their length, into "tube walls." M. Normand lays great stress on using what are technically known as "drowned tubes," that is to say, tubes whose upper ends deliver *below* the water line, in contradistinction to those of the Thornycroft and Mosher boilers, the generating tubes of which deliver above the water-line.

The Normand boiler is extensively used in the French Navy, and has been fitted in the British Navy on a large number of torpedo-boat destroyers, H.M.S. *Pelorus*, and other ships.

The results obtained by M. Normand with this class of

NORMAND BOILER OF *FORBAN.*

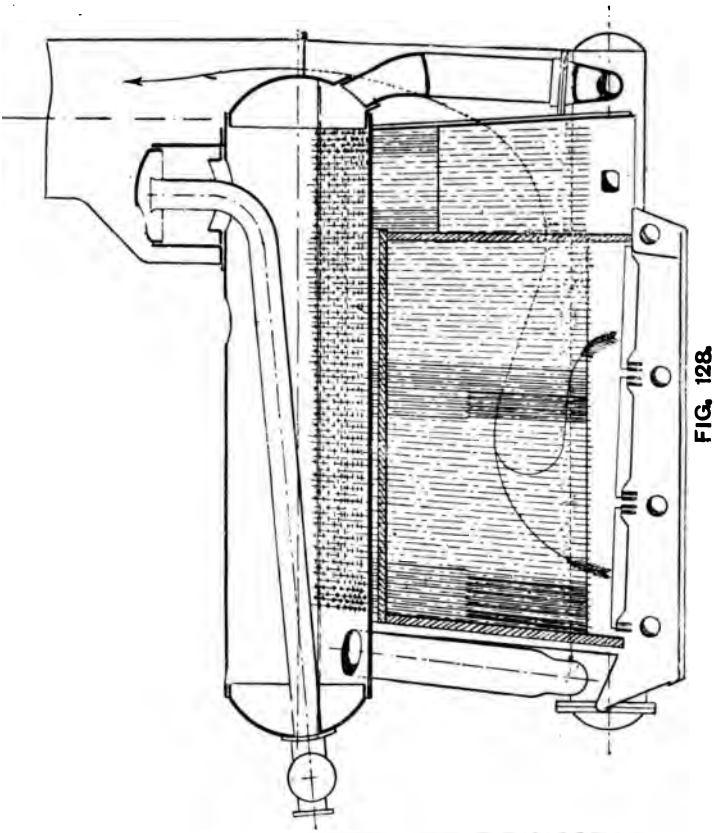


FIG. 128.

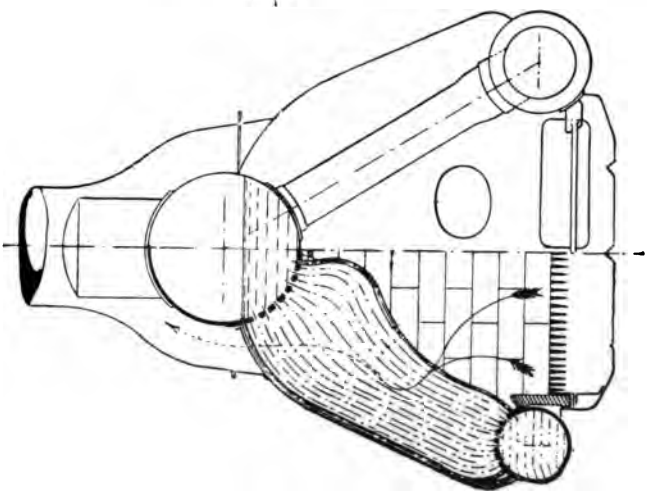


FIG. 127.

boiler have been very interesting, as the following particulars will show :—

	H.M.S. *Ferret*	*Forban*	Direct-flame, *Lance*	Return-flame, *Cyclone*
Number of Boilers . . .	4	2	2	2
Grate Surface, total . sq. ft.	154	88.26	90.4	103.4
Heating Surface, total . ,,	8,112	4,628	4,780	4,866
Ratio $\frac{H.S.}{G.S.}$	52.7	52.4	52.8	47.1
Weight of boilers without water . . . . tons	...	24.4	23.38	24.01
Weight of water . . . tons	...	6.26	5.52	5.5
Weight of boilers complete, with water . . . . tons	50.7	30.66	28.9	29.52
Weight per sq. ft. of grate surface . . . . lbs.	738	778	716	639
Weight per sq. ft. of heating surface . . . . lbs.	14.00	14.84	13.54	13.59
I.H.P.	4,774*	4,121	...	...
I.H.P. per sq. ft. of grate . .	31.0	46.7	...	...
Floor-space per boiler sq. ft.	...	...	122.2	152.7

* Minutes of Proceedings, Inst.C.E., vol. cxix., pp. 29 and 87.

The torpedo boat *Forban* was, at the time of her official trial, the fastest boat afloat, and some additional particulars of her trial may therefore be interesting.

Speed on trial . . . . knots	31.03
Displacement at full speed . . tons	126.3
,, ,, 14 knots . . . ,,	149.7
Consumption of coal at full speed, per sq. ft. of grate . . . . . lbs	63.9
Consumption of coal at 14 knots, per sq. ft. of grate . . . . . lbs.	7.06
Air pressure at full speed . inches of water	4.75
Air pressure at 14 knots . ,,	...
Consumption per I.H.P. at full speed . lbs.	1.36
Consumption per I.H.P. at 14 knots . ,,	0.86

37. Normand-Sigaudy Boiler.—The Normand-Sigaudy boiler (Figs. 129, 130) is practically two Normand boilers placed back to back, with the upper and lower drums connected together. It was brought out by M. Sigaudy of Havre, for use on large cruisers.

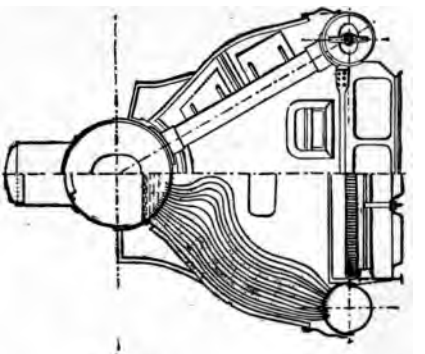


FIG. 130.

NORMAND-SIGAUDY BOILER.

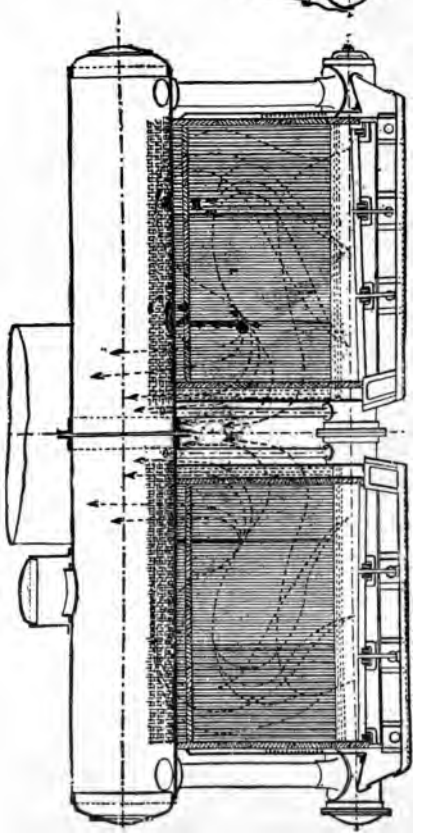


FIG. 129.

The saving of weight by the use of double-ended tubulous boilers is not so great as in the case of double-ended cylindrical boilers, and should one of the boilers give out, a larger proportion of the total power of the vessel is put out of action than if the boilers had been kept in single units. This type of boiler is, however, being fitted on the *Chateau-Renault*, a cruiser of 23,700 H.P.,

under construction at Havre, but the official trials have not yet taken place. The following are particulars of one of the Normand-Sigaudy boilers of the French cruisers *Dunois* and *La Hire.*

Grate Surface	sq. ft.	63.5
Heating Surface	,,	3232
Ratio, $\frac{\text{H.S.}}{\text{G.S.}}$	,,	50.9
Weight of boiler and mountings, but without water	tons	18.21
Weight of water	,,	4.23
Weight of boiler with water	,,	22.44
Weight of boiler per sq. ft. of H.S.	lbs.	15.56
,, ,, ,, G.S.	,,	792
Floor space per boiler	sq. ft.	191.2

38. Mosher Boiler.—The Mosher boiler (Fig. 131), which has been largely used for steam yachts in America, and also for many of the United States torpedo boats, consists of two bottom water drums and two upper steam drums, each water drum and steam drum being joined by curved tubes of about 1″ external diameter, entering the steam drum above the water-line. Two external down-take tubes are fitted on the front of the boiler. The grate is placed between the two bottom drums, and the generating tubes coming from these are curved over the furnace, until the inner rows meet; they then curve outwards again and enter the steam drums, which are on the outside of the boiler. These steam drums have no communication with each other except through the main steam-pipe, so that each side is independent, though the grate is common to both.

The steam and water drums are made of steel, and the tubes of weldless steel tubing.

The crown of the furnace is composed of an unbroken

wall of tubes for three-quarters of the length of the boiler, along which the gases pass to the back of the furnace where the tubes are staggered, forming openings through which the hot gases pass in among the intervening tubes, returning towards the front of the boiler.

MOSHER BOILER.

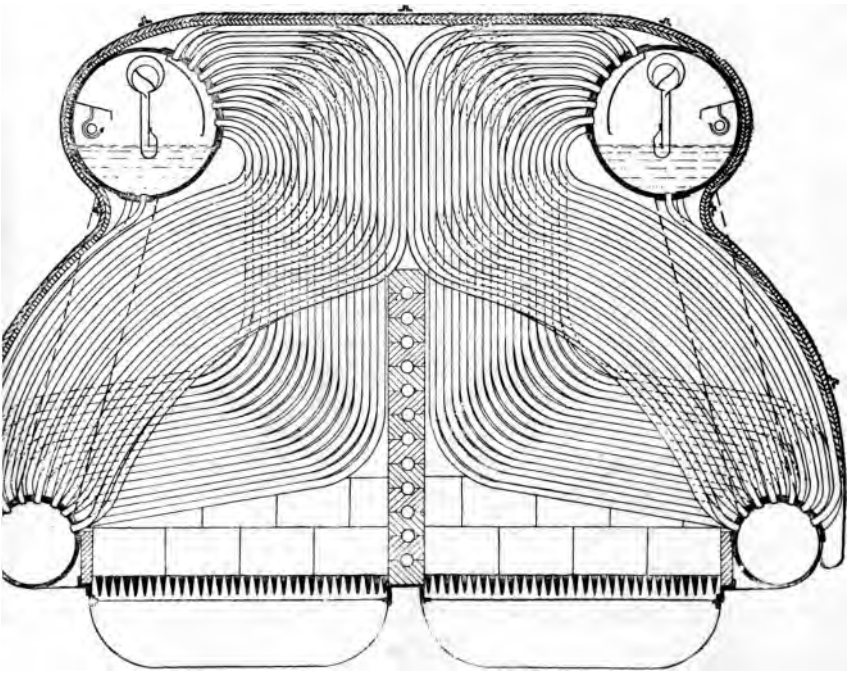


FIG. 131.

The two outside rows of tubes, which enter the bottom of the steam-drum and act as down-comers, are bent between each other so as to form a continuous tube-wall protecting the casing from the heat.

The boilers of the U.S. torpedo-boat *Foote*, the official trials of which were made in 1896, had each a total heating

surface of 2,630 sq. ft. and a grate surface of 47.5 sq. ft, giving a ratio of H.S. to G.S. of 55.39.

The following are some particulars of an eight-hours' natural-draught trial of a Mosher boiler, which was carried out in America.

Heating Surface	sq. ft.	1,108
Grate Surface	,,	33
Ratio $\frac{\text{H.S.}}{\text{G.S.}}$		33.6
Coal per sq. ft. of grate per hour	lbs.	7.1
Water evaporated per lb. of coal	,,	9.12
Wetness of steam	per cent.	1.5
Temperature of funnel gases	Fahr.	442°

The following figures give the heat utilized and lost in the same boiler:—

Heat utilized in evaporating water	76 per cent.
,, lost in funnel	13
,, ,, radiation	9.1
,, ,, evaporating water in ashpan	1.9
	100.0

The launch type of this boiler (Fig. 132) is practically only one-half of the boiler already described. The hot gases, however, on leaving the furnace, first enter at the lower portion of the tubes at the back end, pass upward and forward among the tubes, being deflected by the baffle plate which rests upon the inclined portion of the tubes; they then turn and pass back along the upper portion of the tubes and through a feed-water heater. The drums in this case are placed transversely to the boiler.

39. Reed Boiler.—The Reed boiler (Fig. 133) is very similar to the Normand boiler, and consists of a top steam and water drum and two lower water-chambers, joined by generating tubes very much bent, and delivering below the

water level. The inside row of tubes used to be bent into a wavy form, which was somewhat unfavourable to the free escape of steam: this, we understand, has now been discontinued. There is a large external down-comer at each end. The generating tubes are connected at each end with nuts inside the chambers, in a similar way to the du Temple

MOSHER LAUNCH BOILER.

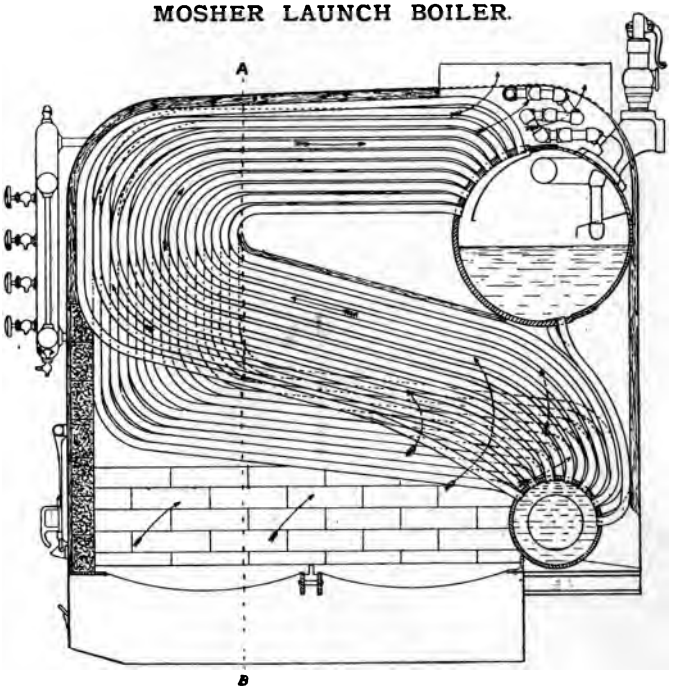


FIG. 132.

boiler, only that the joint instead of being made upon a conical face and a plane face, is made upon two spherical faces, which allows of a certain angular play of the tubes. The generating tubes are of $1\frac{1}{16}''$ outside diameter, reduced at the bottom to $\frac{7}{8}''$, which allows extra space for the entry of the gases among the tubes. Baffles are fitted in the boiler to direct the movement of the hot gases over the tubes. Reed boilers

have been adopted for several English torpedo-boat destroyers, amongst which are the *Janus*, *Lightning*, *Porcupine*

REED BOILER.

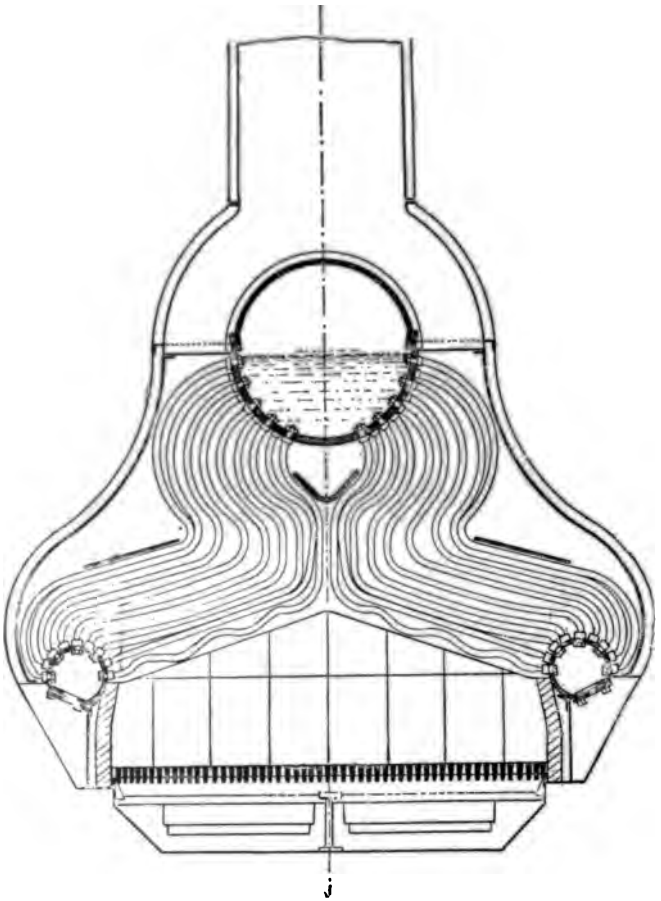


FIG. 133

and *Star*. In a coal-consumption trial on land, 12 lbs. of water, from and at 212° Fahr., was evaporated per lb. of coal.

The following are some particulars (taken on the thirty hours' coal-consumption trial at half speed, and on the full

speed trial) of the Reed boilers of the third-class cruiser *Pegasus.**

	Consumption trial.	Full power.
Number of boilers	8	8
Total Heating Surface sq. ft.	18,876	18,876
Total Grate Surface ,,	360	360
Ratio $\frac{\text{H.S.}}{\text{G. S.}}$	52.4	52.4
I.H.P.	3,698	7,127
Coal per I.H.P. per hour lbs.	1.96	—
Coal per sq. ft. of grate ,,	19.9	—
Weight of boilers, complete * tons	185	185
Weight per sq. ft. of grate lbs.	1,151	1,151
H.S. per I.H.P. sq. ft.	5.10	2.65
I.H.P. per ton of boiler	20	38.5

* Including funnels, casings, and all boiler-room fittings.

40. White Coil Boiler.—In the White coil boiler (Fig. 134), built by Messrs J. S. White of East Cowes, the majority of the tubes joining the three chambers are of spiral form, and divided into three portions by walls of uncoiled tubes, bent into a Z-shape. The hot gases pass among the spiral tubes on the inside of the uncoiled tubes to the back of the boiler, and then return among the spiral tubes on the other side of the uncoiled tubes. In the double boiler,

WHITE COIL BOILER.

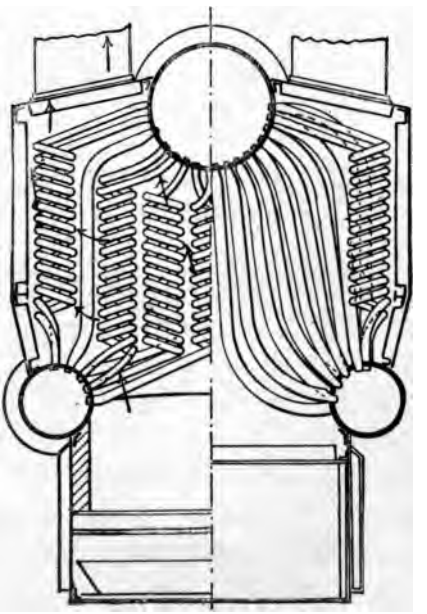


FIG. 134.

* Minutes of Proceedings, Inst.C.E., vol. cxxxvii., part iii.

which has been fitted to some torpedo-boat destroyers, there is a slight modification of this, only three rows of uncoiled tubes being employed, one row being common to both boilers. The uncoiled tubes are reduced at the ends, so as not to cut away too much of the plates of the drums. The front and back ends of the boiler are protected on the inside by large tubes arranged close together.

The following are some of the mean results of the full-speed trials of four destroyers of the *Conflict* class, fitted with White coil boilers *:—

Number of boilers	3
Total Heating Surface . . . sq. ft.	11,250
Total Grate Surface . . . ,,	212.5
Ratio $\frac{\text{H.S.}}{\text{G.S.}}$	52.9
I.H.P.	4,931.6
Weight of boilers, complete * . . tons	83
Weight per sq. ft. of grate . . . lbs.	875
Heating Surface per I.H.P. . . sq. ft.	2.28
I.H.P. per ton of boiler	59.4

* Including funnels, casings, and all boiler-room fittings.

41. Ward Coil Boiler.—The Ward boiler has been in use for some considerable time in the United States Navy. There are several different types, the two principal being the coil boiler (Fig. 135) fitted to the *Monterey*, and the launch boiler (Figs. 136, 137). The Ward boiler fitted on the U.S. coast-defence vessel *Monterey* (in conjunction with cylindrical boilers) is a coil boiler, and consists of a central vertical drum surrounded by concentric coils or sections, A. Each section has a number of complete half circles of tubes placed one above the other. The tubes of each section are connected in half circles by screwed joints to two vertical headers, BB, diametrically opposite to each other. The tubes, A, are

* Minutes of Proceedings, Inst.C.E., vol. cxxxvii., part iii.

WARD COIL BOILER.

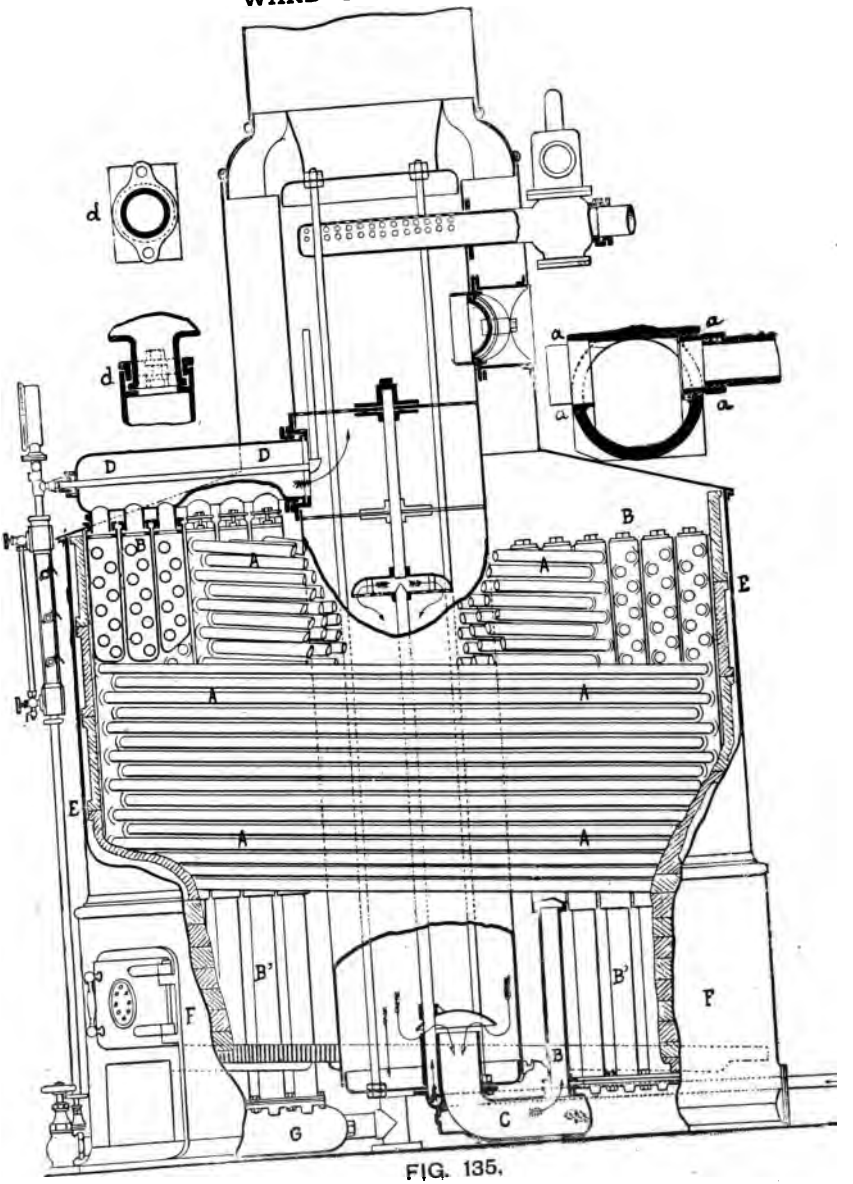


FIG. 135.

about 2″ in diameter, and are set at an angle of about 10° with the horizontal to give direction to the current of circulation in them.

The central vertical drum receives the feed-water from an internal pipe that passes through its lower portion and extends to near the water-line. The space above the water-line in the central drum forms practically all the steam-space.

The headers, B, carrying the lower ends of the tubes, A, have a common connection at their bottom ends through pipes, B', with a water-collector, C. This collector communicates with the central drum, and supplies the headers, B, with water. The upper ends of the headers are closed.

The headers carrying the highest ends of the half circles connect with a horizontal receiver, D, at their upper ends, through which all steam generated passes into the top portion of the central drum. At their lower ends they connect with a bottom collector, G, which serves as a mud-drum. The headers proper do not extend below the level of the generating tubes, the connections with the lower water-collectors, G and C, being made through iron pipes, B', of about $3\frac{1}{2}$″ diameter, screwed into the bottom ends of the headers, and joined to the water-collectors by shallow stuffing-boxes. The bottom collectors are below the grate, and they and the headers are of cast steel. The grate is circular, and composed of segments placed around the central vertical reservoir. The central reservoir is divided into two parts by a horizontal partition; the feed-water finds its way down to the horizontal collector, C, and the steam issuing from the generating tubes is received at the upper end of the central reservoir.

All the joints are very simple, and the entire boiler should have great elasticity, owing to the curvature of the generating tubes. Its principal disadvantage is the circular form of the

grate, which renders the stoking difficult, especially at the sides, and necessitates clear room for stoking all round the boiler.

The Ward boiler is one of the lightest in existence, the two boilers of the *Monterey*, with a total of 73.74 square feet of grate surface, weigh 15.08 tons without water and 17.5 tons with water, which makes only 532 lbs per square foot of grate. This type of boiler has been fitted on four of the U.S. revenue cutters.

The following are some particulars of a Ward coil boiler tested under forced draught: *—

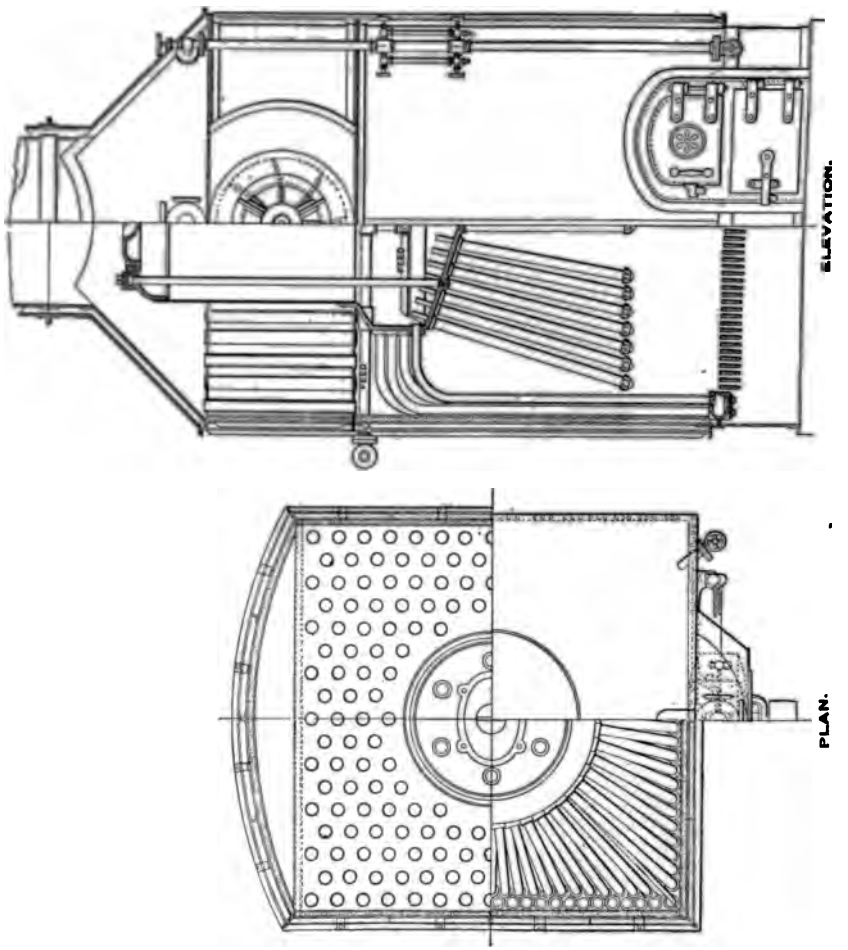
Heating Surface	sq. ft.	2,473.5
Grate Surface.	,,	53
Ratio $\frac{\text{H.S.}}{\text{G.S.}}$		46.67
Weight of boiler, empty	tons	11.84
,, water	,,	2.01
,, boiler and water . . .	,,	13.85
,, ,, per sq. ft. of grate . .	lbs.	585.3
,, ,, ,, H.S. . .	,,	12.5
Evaporation from and at 212° Fahr. .	,,	7.31
Coal per sq. ft. of grate	,,	55.05

42. Ward Launch Boiler.—The Ward launch boiler (Figs. 136, 137), of which there are a good many in use in the U.S. Navy, differs considerably from the preceding boiler. It is constructed of vertical water-tubes completely surrounding the grate and forming the walls of the boiler. The tubes are connected at their lower ends by screwed joints with right- and left-handed threads to a water-chamber or pipe, and are bent over at the top to enter the lower part of a vertical steam and water drum.

A number of closed-ended tubes with an internal circulat-

* "Journal of the American Society of Naval Engineers," vol. ii. No. 4.

ing tube are suspended over the furnace from the bottom of the upper steam and water drum, which is cone-shaped. The



boiler is made either cylindrical or rectangular in plan. The boiler is fitted with a fan, and a heater for warming the air supplied to the boiler.

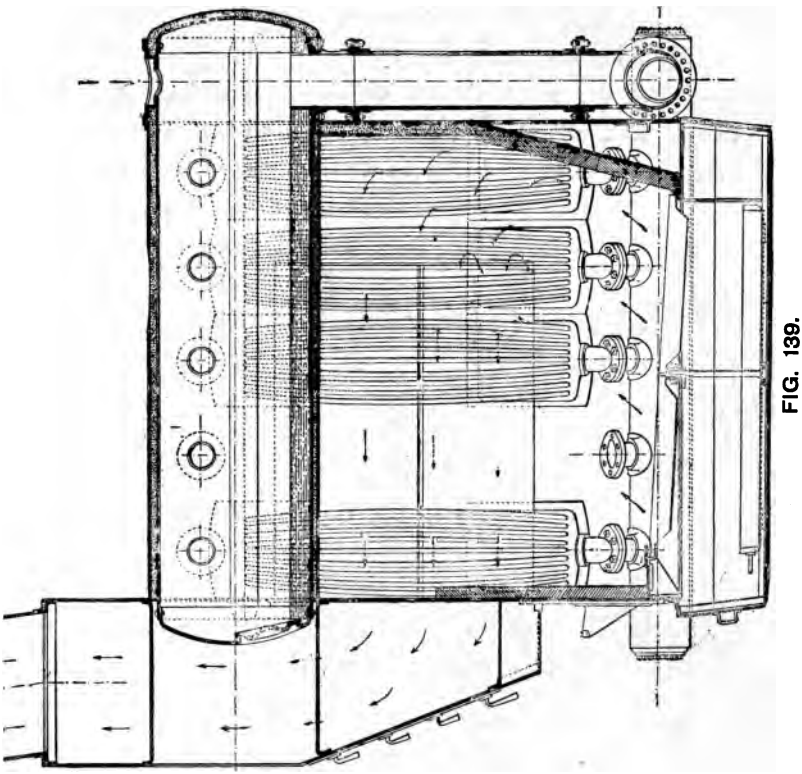


FIG. 139.

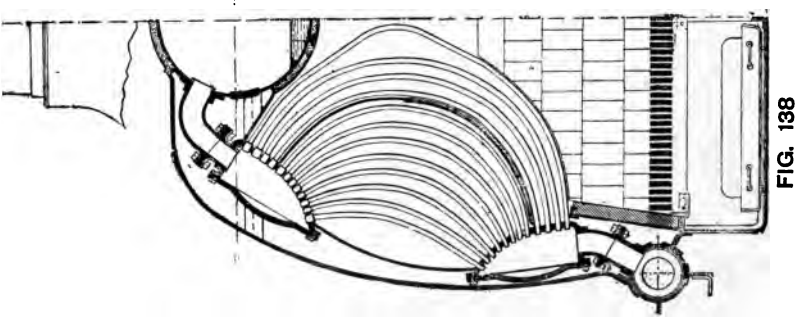


FIG. 138

43. Mumford Boiler.—The Mumford water-tube boiler (Figs. 138, 139) is similar to other water-tube boilers of this class in possessing one central upper steam and water drum, and two lower smaller water drums connected by small generating tubes. Instead of the generating tubes, which are of galvanised steel, being expanded direct into the drums above mentioned, they are expanded into square forged steel boxes situated near these drums, and connected directly to them. Doors fitted on the back of the square boxes giving access direct to the tubes. The boxes are themselves connected by means of flanges and bolts to the large tubes joining them to the top and bottom reservoirs, and thus have the advantage that should it be desired to remove any section, it can be easily lowered into the furnace, removed through the front of the boiler, and another one substituted. One of these sections is shown in Fig. 140. A single tube can be stopped by merely taking off the doors of the boxes. A large down-comer is fitted at the back of the boiler to return the water from the top to the bottom drums.

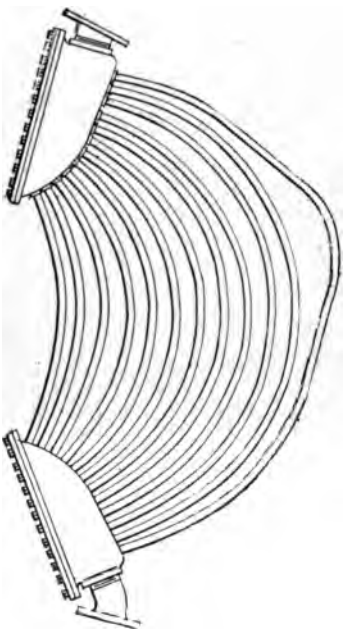


FIG. 140.

The gases can either be arranged to pass off through the funnel situated in the centre of the boiler, or by means of suitable baffles the flames can be forced to pass to the end of the boiler and thence back to the funnel, which is then

situated in the front of the boiler. This latter arrangement naturally gives much more economical results, as the flames are much longer in contact with the tubes, and the course of the flames is at right angles to the direction of the tubes. The boiler stands forcing well. 150 lbs. of coal have been burnt per sq. ft. of grate, and 22 lbs. of water have been evaporated per sq. ft. heating surface. Due to the form of the boiler it is evident that the weight per sq. ft. of H.S. is more than in some of the other small-tube boilers.

Four 1,000 H.P. boilers are fitted on board H.M.S. *Salamander*, and the following are the results obtained from one of these boilers on the Admiralty official tests :—

Duration of trial	hours	4
Heating Surface	sq. ft.	2,000
Grate Surface	,,	45
Ratio $\frac{\text{H.S.}}{\text{G.S.}}$		44·4
Lbs. of water per lb. of Coal		9
Coal per sq. ft. of grate	lbs.	25
Temperature of feed	Fahr.	56°
Steam pressure	lbs. per sq. inch	175
Air pressure	inches of water	0.15
Lbs. of water per lb of coal from and at 212°		10.9
Weight of boiler, empty	tons	18.35
,, water	,,	2.15
Total weight of boiler and water	,,	20.5
Weight of boiler per sq. ft. of H.S.	lbs.	22.96
,, ,, G.S.	,,	1,020.5

The small boilers for torpedo-boats, Nos. 63 and 64, are similar to the *Salamander* boilers as far as the form of the generating tubes is concerned, but differ from them in that the tubes are expanded direct into the top and bottom drums, and the section arrangement has therefore been

suppressed. The results of trials on these boilers are as follows:—

Grate Surface	sq. ft.	22
Heating Surface	,,	850
Ratio $\frac{H.S.}{G.S.}$		38.7
I.H.P.		400
Temperature of feed . . .	Fahr.	58°

Lbs. of coal per sq. ft.	Lbs. of water evaporated per lb. of coal.
25	9.88
50	9.05
75	7.4
100	6.317

44. Fleming and Ferguson Boiler.—The Fleming and Ferguson boiler (Fig. 141) is composed of a large central upper steam and water drum connected below the water-line by banks of curved generating tubes to two lower water drums. The top drum is of such diameter that any of the small bent generating tubes can be drawn into it for removal. The I.H.P. per ton of boiler is about 26.5.

45. Blechynden Boiler.—The Blechynden boiler (Fig. 142) is very similar in design to the Yarrow boiler described below, but the two lower water-chambers are rather larger. At the top of the steam drum there are a series of hand-holes arranged along the length of the boiler, sufficiently close to allow of the introduction or removal of any of the tubes independently of the others, the tubes being slightly curved to arcs of 30 and 50 feet radius respectively, depending on their position, and converging on these hand-holes. In the earlier boilers there were two rows of these holes, one on each side of the centre line, but as now made there is only one row. There was also a wall of tubes formed by the two outside rows of tubes being bent in between each other in the usual way, leaving a space for the hot gases to escape at the top, but this has now

been discontinued. The tubes discharge their steam and water below the water-line, and originally there were no external down-comers, the water returning to the bottom

FLEMING AND FERGUSON BOILER.

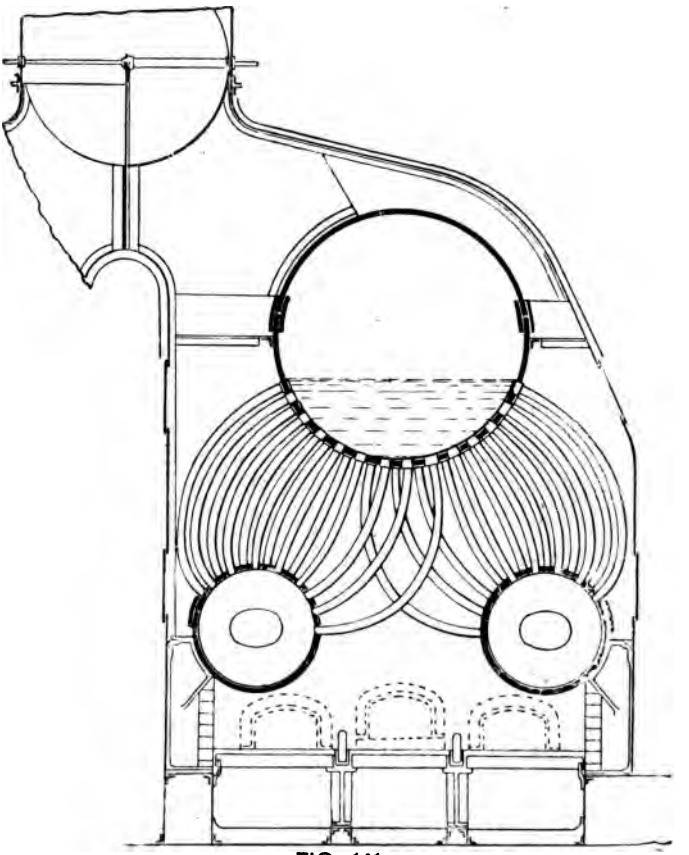


FIG. 141.

drums through the outside row of tubes. Now, however, four down-comers, $3\frac{1}{2}''$ diameter, are fitted at each end between the steam drum and bottom collectors. This boiler has been fitted in the Navy on three destroyers and two third-class cruisers, and on several torpedo-boats.

The following are some of the mean results of the full-

BLECHYNDEN BOILER.

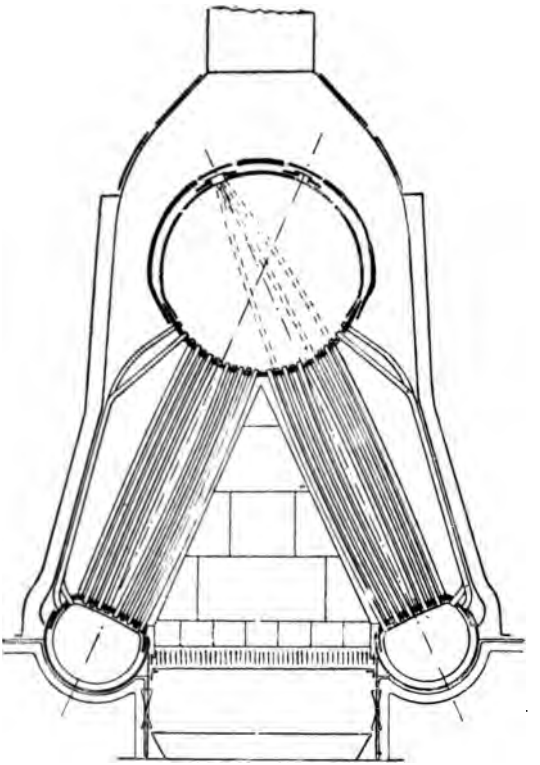


FIG. 142.

speed trials of three destroyers of the *Sturgeon* class, fitted with Blechynden boilers.*

Number of boilers	4
Heating Surface . . . . . sq. ft.	10,022
Grate Surface . . . . . ,,	176
Ratio $\frac{\text{H.S.}}{\text{G.S.}}$	56.9
I.H.P.	4,367
Weight of boilers complete † . . . tons	62.2
Weight per square foot of grate . . lbs.	785
Heating surface per I.H.P. . . sq. ft.	2.29
I.H.P. per ton of boiler	70.2
Coal per I.H.P. per hour . . . . lbs.	3.29

† Including funnels, casings, and all boiler-room fittings.

* Minutes of Proceedings, Inst.C.E., vol. cxxxvii., part iii.

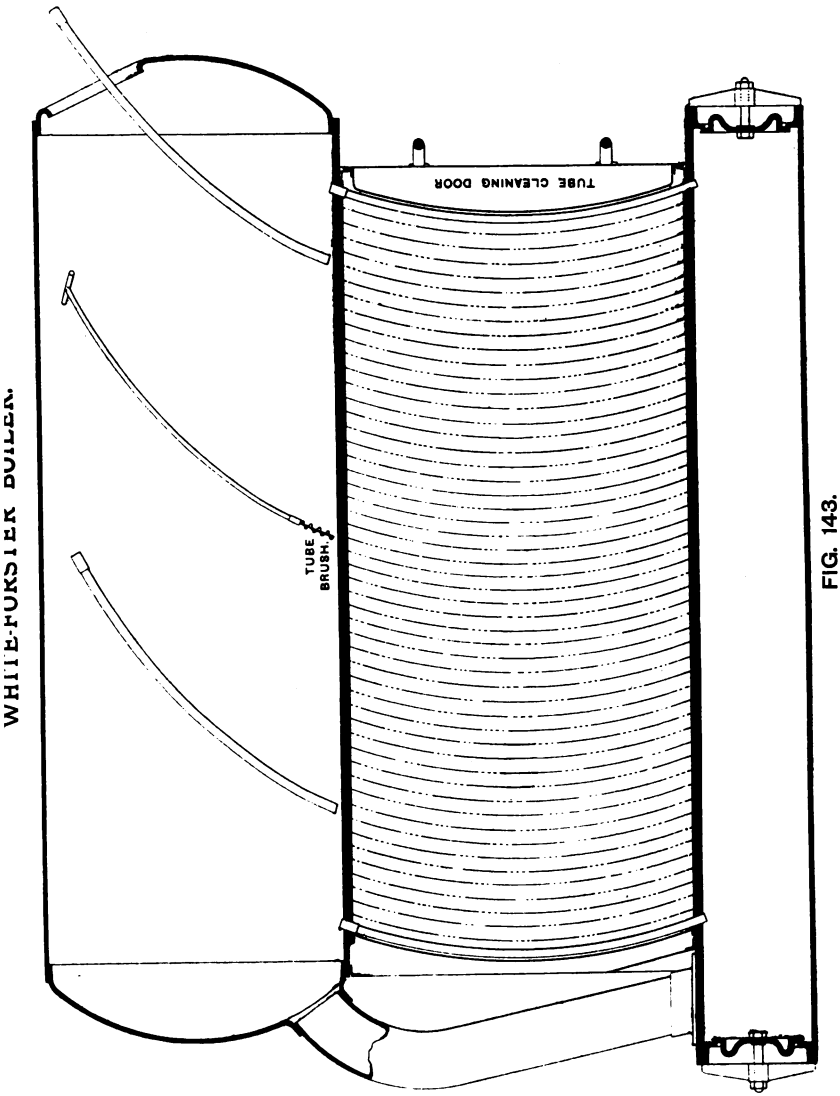


FIG. 143.

46. White-Forster Boiler.—Messrs White brought out in 1898 another form of small tube boiler, called the White-Forster boiler (Figs. 143, 144). As will be seen, it consists of the usual steam and water drum, connected by banks of small "drowned" generating tubes to two bottom water drums, the grate being situated between them. These small tubes are all curved to the same radius, and each tube can be withdrawn into the top drum when it becomes necessary to replace a tube. Owing to the curved form of the tubes, the top drum can be made of smaller diameter than is usually the case in boilers where the tubes are withdrawn into the top drum, and a rigid tube brush can be used for cleaning the tubes. Large external down-comers are fitted to the back of the boiler. The boiler is being fitted to a number of boats in the British and foreign Navies.

47. Yarrow Boiler.—In the Yarrow boiler (Fig. 145) there is an upper central steam and water drum and two lower water drums connected by straight tubes, which enter the upper drum below the water-line. In the small types (Fig. 146) the steam drum is made in two portions, which are bolted together, the top being removable to facilitate access to the tube ends. In large boilers upper barrels with bolted joints could not be constructed capable of supporting the pressure, and so they are made with the usual riveted joints (Fig. 147). In consequence of this, they lose the advantage possessed by the divided barrels; but this is not of much importance, as their large size permits of ready access for the examination and replacing of tubes. The bottom ends of the tubes are expanded into a tube plate, to the under side of which a small water-chamber is bolted. The original type of this boiler, fitted on a torpedo-boat, had external down-comers. In the torpedo-boat destroyer *Hornet*, these down-comers were omitted, the

water returning down the rows of generating tubes farthest from the fire. A few of these tubes are sometimes screened

WHITE-FORSTER BOILER.

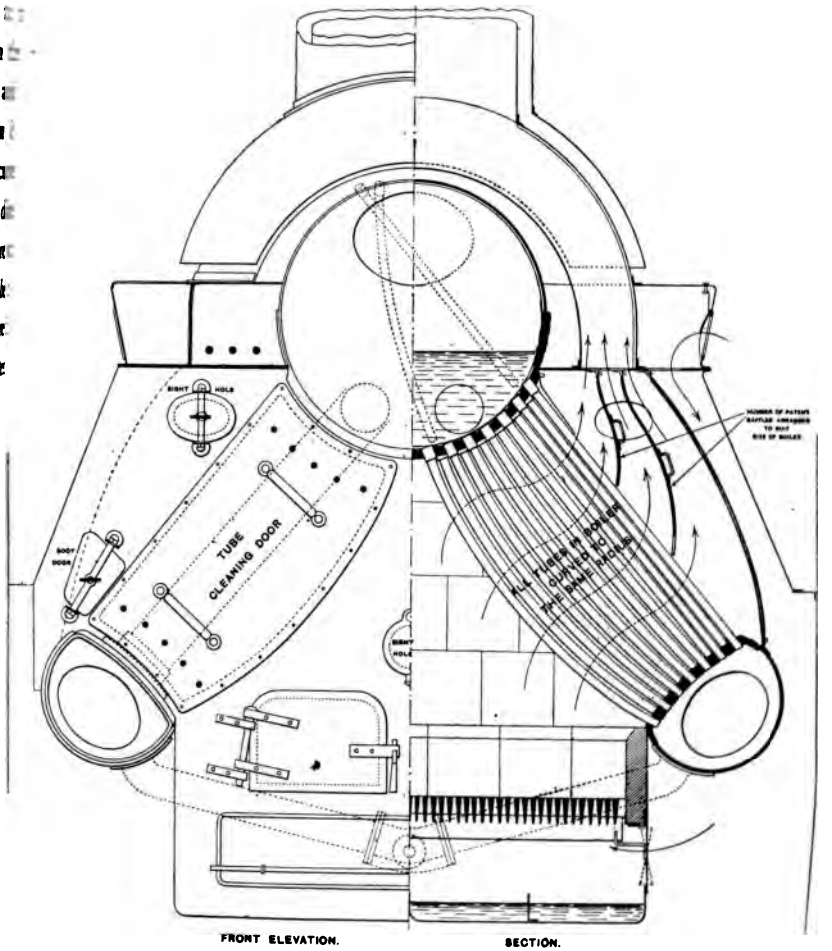


FIG. 144.

or shielded from the fire at the ends by means of baffle plates between the tubes to keep them cool, and so facilitate the return flow of water to the lower drums. Some of these

boilers have had small return tubes fitted at each end, which also act as stays to the boiler. The casings of the boilers are portable to allow of removal for cleaning the outsides of the tubes. The feed-water is introduced into the upper drum.

It was at first thought that, owing to the tubes being

YARROW BOILER.

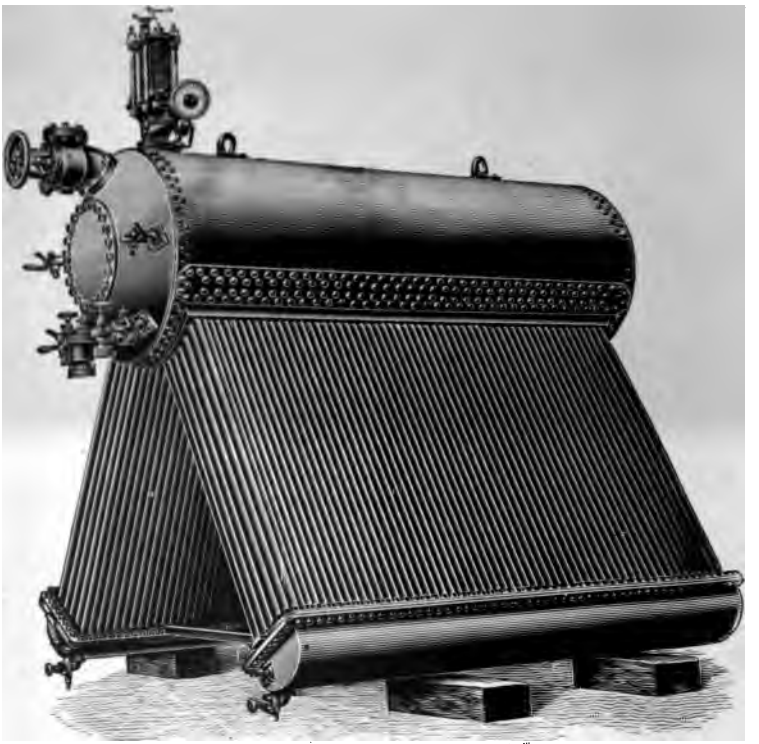


FIG. 145.

straight, the joints would be started in cases of unequal expansion. This, however, is not found to be the case in practice, as any small difference in length seems to be met by the elasticity of the material. Tubes of different materials have been used for these boilers. At first steel tubes were

employed, but afterwards were discarded in favour of brass ones. At the present time Messrs Yarrow are using solid drawn steel tubes of from 1″ to 1½″ in diameter, and averaging 0·08″ in thickness.

YARROW BOILER—TORPEDO-BOAT TYPE.

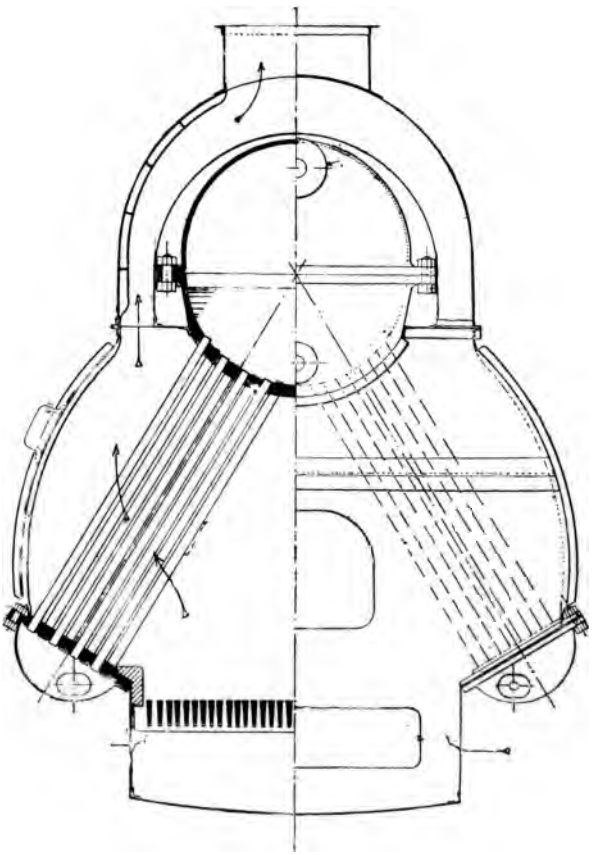


FIG. 146.

The Yarrow boiler has been fitted on ten of the torpedo-boat destroyers, on a larger number of torpedo-boats in our Navy, and on many foreign ones, besides several foreign gun-boats and third-class cruisers.

The great advantage of the Yarrow boiler lies in its straight tubes, which enables them to be inspected and cleaned with an ordinary-pattern tube scraper. The boiler is a light and compact boiler for its work, but due to the shortness of the tubes, the ratio of H.S. to G.S. must be

YARROW BOILER.

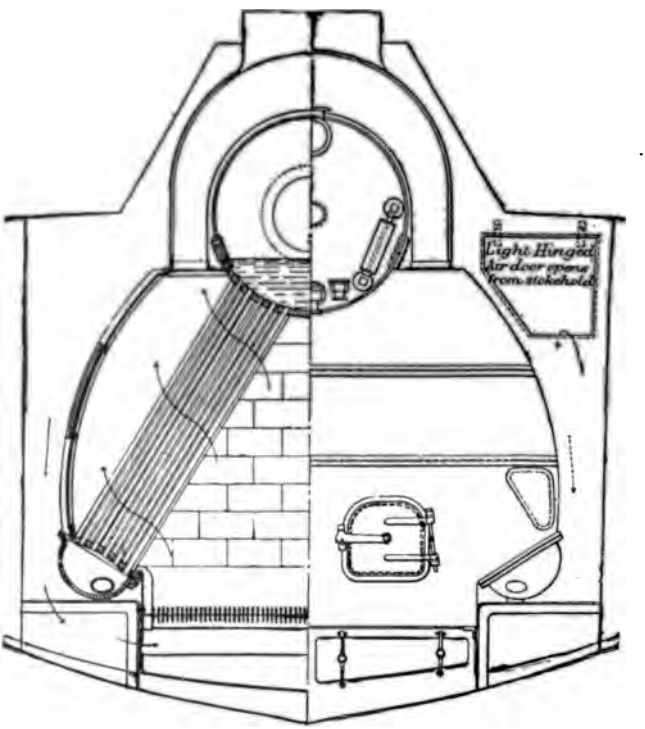


FIG. 147.

somewhat low, and due to this and to the short travel of the gases, funnel temperatures are apt to be slightly high. The course of the gases, though transverse to the tubes, is really comparatively short: the combustion chamber is lofty and roomy.

The following are some of the mean results of the full-speed trials of two destroyers of the *Swordfish* class, fitted with Yarrow boilers.*

Number of boilers		8
Heating Surface	sq. ft.	7,694
Grate Surface	,,	162.4
Ratio $\frac{\text{H.S.}}{\text{G.S.}}$		47.4
I.H.P.		4,551.0
Weight of boilers complete †	tons	62
Weight per sq. ft. of grate	lbs.	855
Heating surface per I.H.P.		1.69
I.H.P. per ton of boiler		73
Coal per I.H.P.	lbs.	3.03

† Including funnels, casings, and all boiler-room fittings.

* Minutes of Proceedings, Inst.C.E., vol. cxxxvii., part iii.

CHAPTER V

Boiler Accessories—Reducing Valves—Belleville Reducing Valve—Belleville Automatic Steam Separator—Automatic Feed-Water Regulators — Belleville — Thornycroft — Sigaudy — Normand-Sigaudy · Yarrow—Niclausse—Weir—Necessity for pure Feed-Water—Filtering—Feed-Water Filters—Harris—Rankine—Mills-Berryman—Filters working at Atmospheric Pressure—Normand —Feed-Water Heaters — Kirkaldy— Normand —Weir —Weight and Space occupied by various types of Boilers—Advantages and Disadvantages of Water-Tube Boilers—Durability of Water-Tube Boilers—General conclusions.

48. Boiler Accessories.—In water-tube boilers the various accessories play a far more important part in their working than in cylindrical boilers. Owing to the comparatively small quantity of water they contain, the regularity of the feed is of *vital* importance. This has led to the introduction of special fittings or accessories to regulate the feed automatically, which are known as *feed-regulating valves.* The generation of steam being far more rapid, and there being little or no steam-space compared to cylindrical boilers, should the rate of firing or the rate of taking steam from the boiler vary, the pressure will fluctuate through far wider ranges than in cylindrical boilers. To avoid corresponding fluctuations in the speed of the engines, and for other reasons, *reducing valves* have been fitted, notably in connection with the Belleville boiler. Further, at a high rate of working or with a sudden change in the rate of working, water is very apt to

be carried over with the steam into the steam-pipe, and as this may lead to grave accidents should it find its way into the engines, *separators* or steam-dryers are fitted in the main range of steam-pipes. It is true that these fittings or accessories are not integral parts of the boiler itself, but the smooth working of the boiler entirely depends upon them. Other accessories in connection with the feed-water, besides the feed-regulating valves, are the *feed-filters*, and *feed-heaters*. We will therefore treat the accessories under two heads.

(1) Those in connection with the steam, such as reducing valves and automatic steam-separators, or dryers.

(2) Those in connection with the feed, such as feed-regulating valves, feed-filters, and feed-water heaters.

49. Reducing Valves.—A reducing valve, though strictly speaking not an integral part of the boiler proper, is, in such cases as the Belleville boiler, an absolute necessity. The advantages of its use are threefold.

(1) It enables one of the principal features of the water-tube boiler to be taken greater advantage of, namely, the use of high pressures, and that without at the same time subjecting the main engines to excessive pressure.

(2) It wire-draws the steam, slightly superheats and dries it.

(3) Considerable fluctuations of pressure may take place in the boiler itself without affecting the pressure at the engines.

50. Belleville Reducing Valve.— The Belleville reducing valve (Fig. 148) consists of a valve attached by means of a plunger D to the end of a lever E, and the pressure in the valve casting always tends to lift this plunger and close

the valve. This is counteracted by means of a set of springs H, whose tension can be altered by a hand-wheel and screw, F. As the pressure on the plunger increases, it tends to close the valve and increases the tension on the springs; this reduces

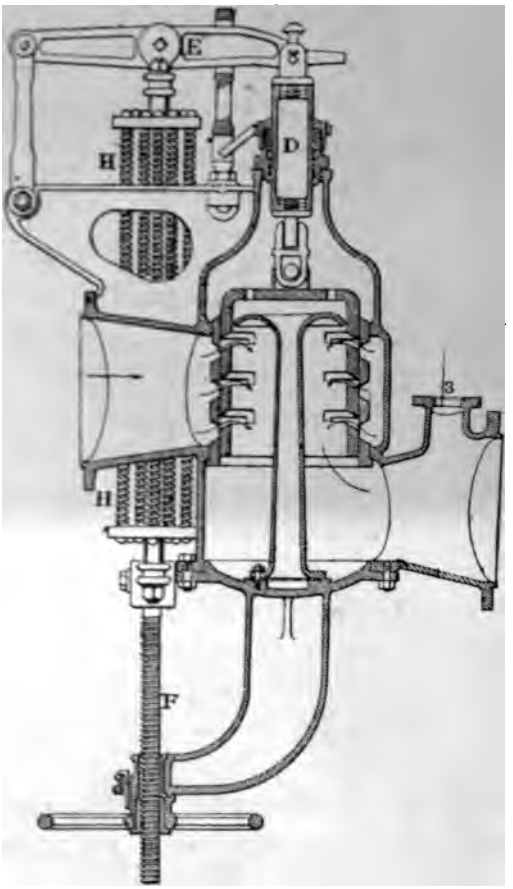


FIG. 148.

the valve openings, thereby restricting the flow of steam, and consequently reducing the pressure on the plunger D, allowing the springs to again pull down the plunger and open the valve. A safety valve is fitted on the reduced pressure side

at 3, and pressure gauges are fitted to both sides of the valve.

There are numerous other types of reducing valves, but we need not go further into them, as the mode of working is very similar.

51. Belleville Automatic Steam Separator.—In order to rid the steam of the water that may have been condensed in the steam piping, or carried over from the boiler, and so ensure dry steam being delivered to the engines, some form of steam-dryer or separator is usually fitted between the boiler and the engines. The Belleville automatic separator (Fig. 149) consists of a cylindrical receiver, furnished with two steam openings for the inlet and outlet of the steam. The steam enters at the top of the separator, and is compelled by means of a partition to descend in order to enter the annular space *b*, in which the orifice for the outlet of the steam is placed. This orifice is considerably smaller than that by which the steam enters, in order to prevent as far as possible sudden alterations of pressure in the separator, and keep the water in the bottom of the cylinder from being

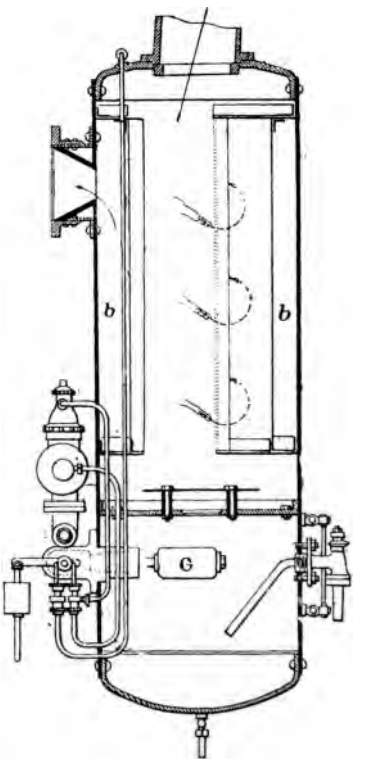


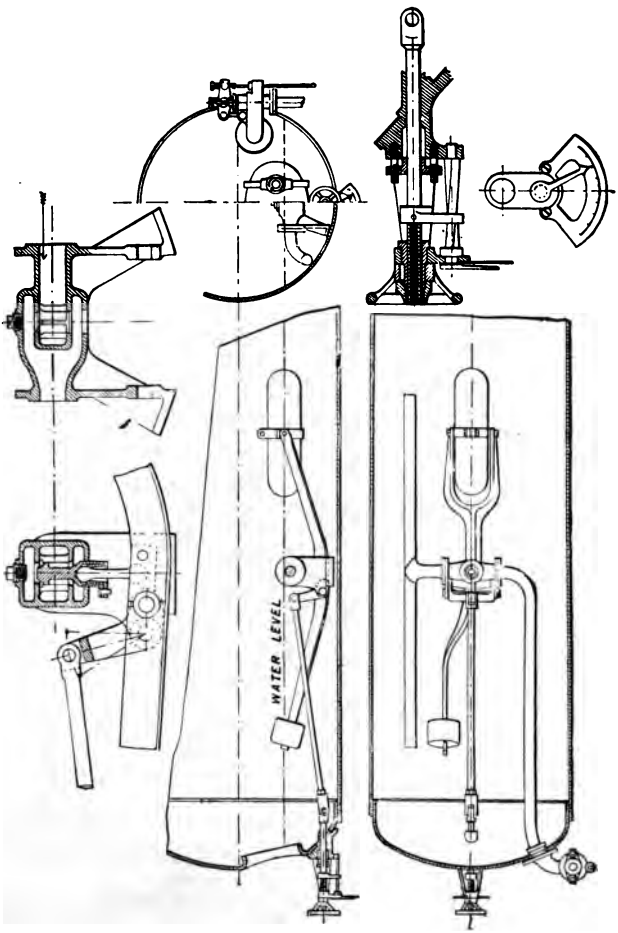
FIG. 149.

[illegible] over with the steam. The separator is drained by an ingenious automatic trap. The float G for the trap, which is [illegible] in the bottom of the separator, does not, however, act directly on the main-cock itself, as is most usually the case, but works a small steam piston, which in its turn works the [illegible] gear.

[illegible] Automatic Feed-Water Regulators. Belleville Feed-Water Regulator.—The provision of an automatic [illegible] is desirable in the case of water-tube boilers [illegible] a small reserve of water. The feed-regulator in[illegible] A. Belleville, and at present attached to his boilers, has varied very little from his original design. It consists (Fig. 150) of a chamber A, containing a float B, actuating the lever C, which works a valve-spindle F, and regulates the opening of the valve and the speed of the water passing to the boiler. When the water-level is normal, the valve closes and is kept shut by means of a spring *k*, and weights *g* at the end of the lever. On the water-level falling, the float falls with it, and by means of the bell crank lever C, raises the end of the lever E on the side which was held down by the spring and weights, and depresses the other end of the same lever

FIG. 150.

to which is hinged the feed-valve spindle F, thus opening the valve and admitting water to the boiler. Directly the water reaches the working level the float ceases to act through



THORNYCROFT FEED-WATER REGULATOR.

FIG. 151.

the lever C on the lever E, which is pulled down by the spring and weights, and closes the valve. A rod is provided for working the lever by hand independently of the float. The vessel in which the float works is placed on the column

ading from the separator to the feed-collector. The suc-
essful working of the Belleville boiler hangs upon this feed-
egulator, as the water-level is so disturbed in the boiler itself
it it would be practically impossible to tell where the
vater-level was, were it not for this fitting.

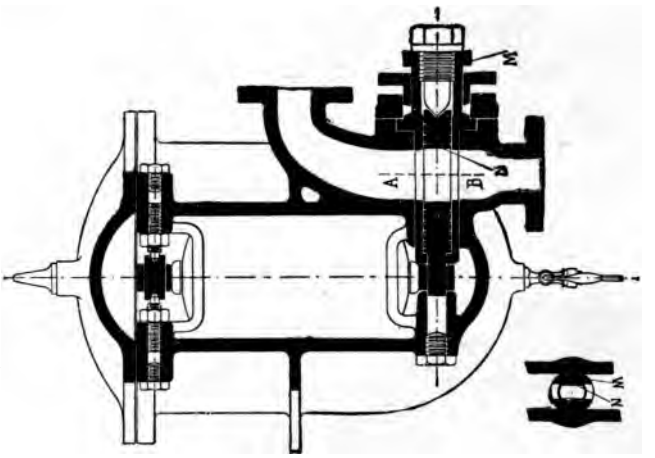
The level of the water in the float-chamber can be varied
y means of the external dead weights *g*, attached to the
ver E, and the water-level has to be varied with the
fferent rates of working, so as to give the head required to
produce the circulation of the mixture of water and steam in
the tubes of the elements. The Belleville regulator works
with extreme regularity, and is thoroughly reliable.

53. Thornycroft Feed-Water Regulator.—The Thorny-
ft feed-regulator (Fig. 151) consists of a float attached to
lever actuating a double-beat valve. The weight of the
it is balanced by a counterweight. The position of the float
can be varied from the outside by means of a hand-wheel
and screw, and an indicator is fitted so as to show its
position. As the water-level varies the movement of the
float throttles or opens the passages through the double-beat
valve.

54. Sigaudy Feed-Water Regulator. — M. Sigaudy
designed a feed-water regulator for use on board the *Jeanne
d'Arc*, which consists (Figs. 152, 153) of a float and counter-
balance suspended between two pairs of levers, the fulcrum
of the levers actuating the plug of a cock outside the float-
gear casting.

55. Normand-Sigaudy Feed-Water Regulator.—T
Normand-Sigaudy feed-water regulator consists of

SIGAUDY FEED-WATER REGULATOR.



Section on A B.

FIG. 153.

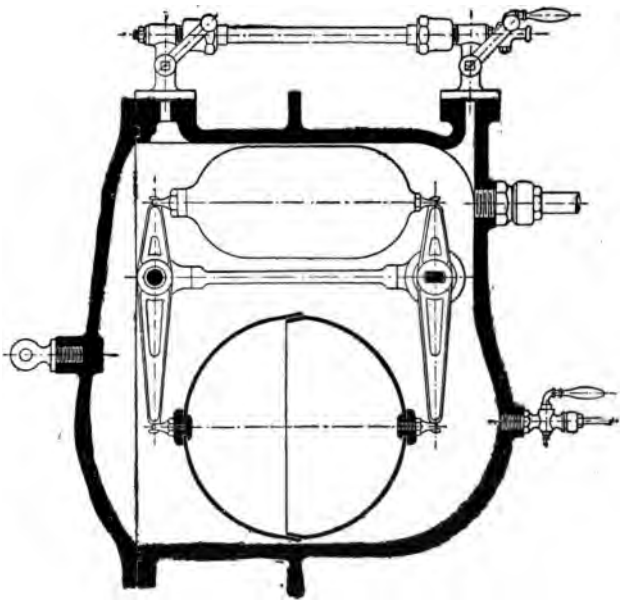


FIG. 152.

A (Fig. 154) placed outside the boiler, in which works a float B, with a counterbalance C, through a lever D. A cylindrical valve E, worked by the float B, regulates the supply of feed to the boiler. The valve E has a central hole to equalise the pressure. The regulator is usually

NORMAND-SIGAUDY FEED-WATER REGULATOR.

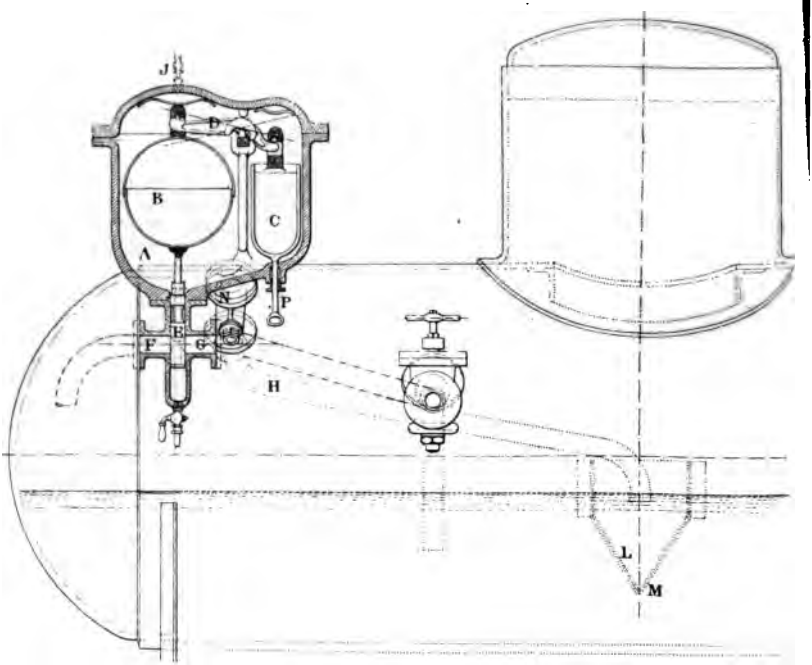
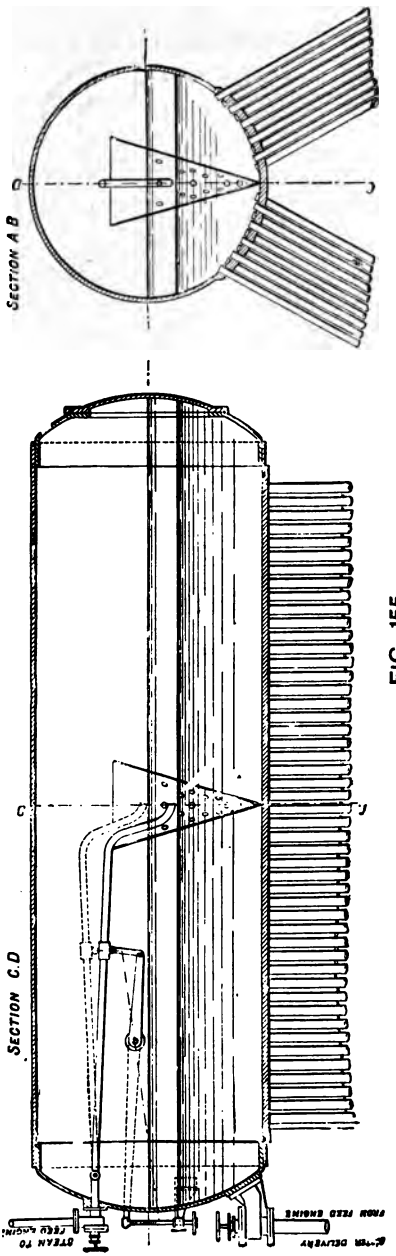


FIG. 154.

placed slightly above the normal feed-level, and connects with the steam and water drum through a cock N, on to which is attached an internal pipe H, running down into a V-shaped receptacle L, near the centre of the steam drum. The receptacle L has a small opening at the bottom M, which secures it being filled with solid water. A small orifice, J, at the top of the chamber A causes a slight ascending

current in the tube H. If the water-level in the main drum is below the opening of the internal tube, steam will pass up the pipe H. If the water-level is above it, water will pass up this tube into the casting A. As the water passes into A, it raises the float and reduces the opening of the valve E. This diminishes the supply of feed-water, the level in the boiler drops, and uncovers the lower end of the internal pipe H, and allows the level in the casting A to drop, and again opens the valve E.



YARROW FEED-WATER REGULATOR.

FIG. 155.

56. Yarrow Feed-Water Regulator.—Mr Yarrow used in connection with his boilers an arrangement (Fig. 155) whereby, when the

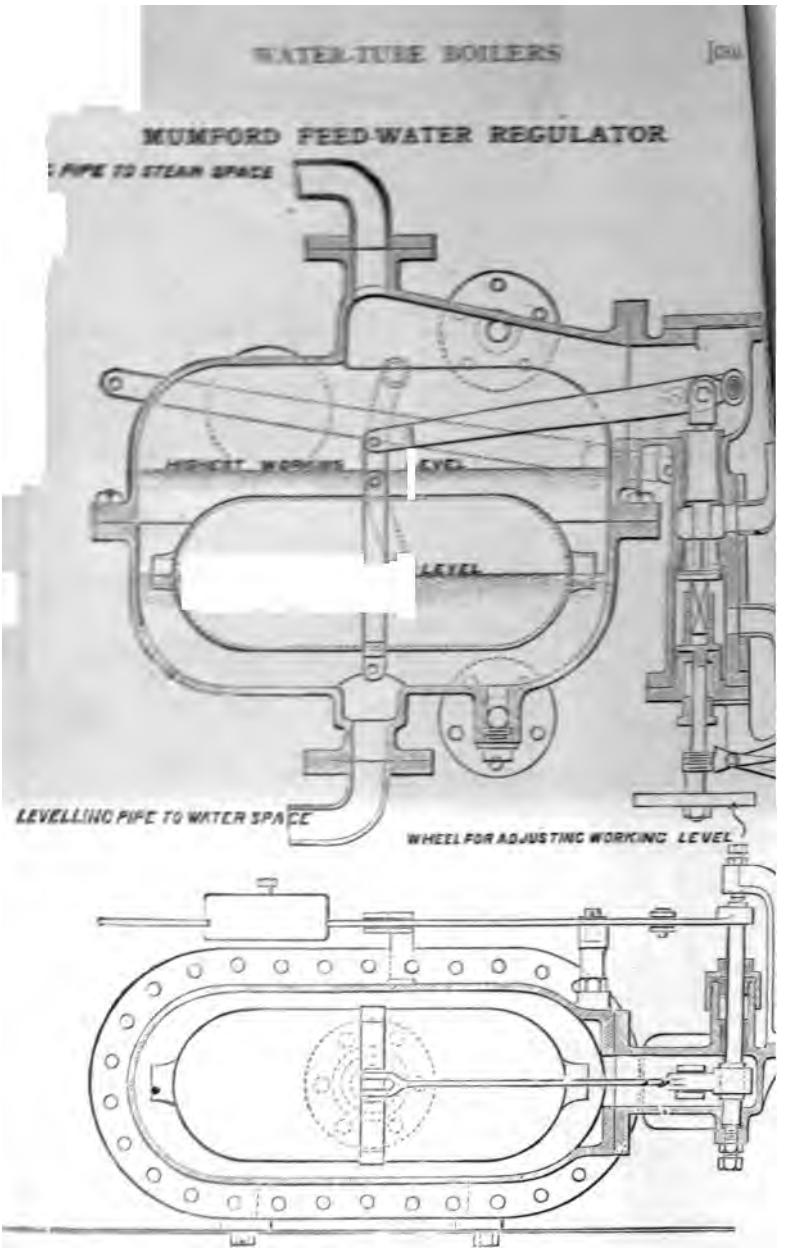
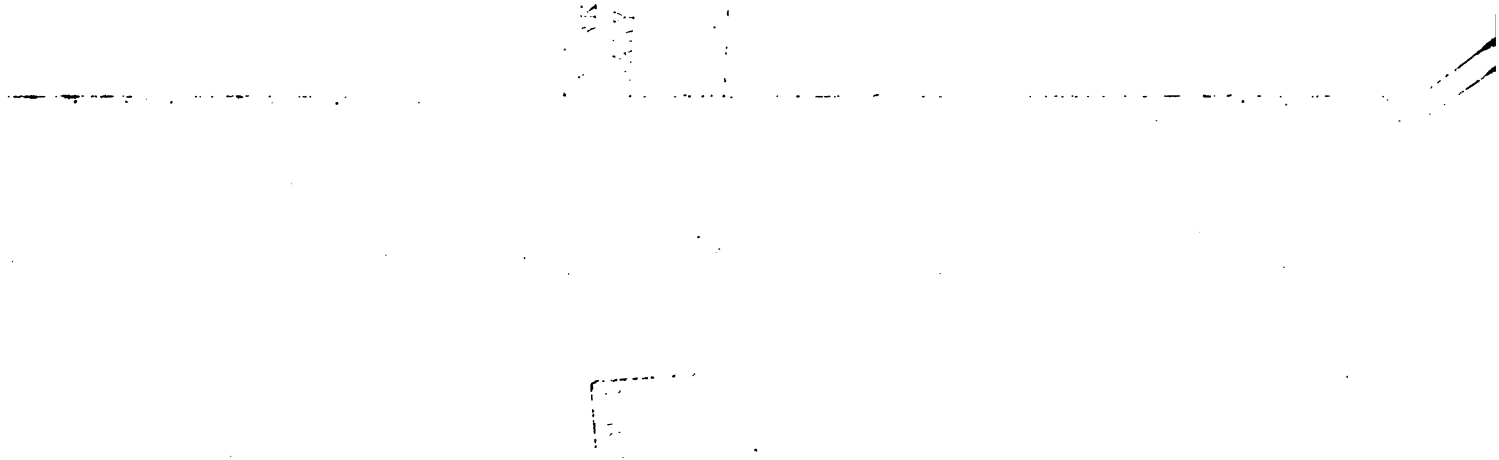
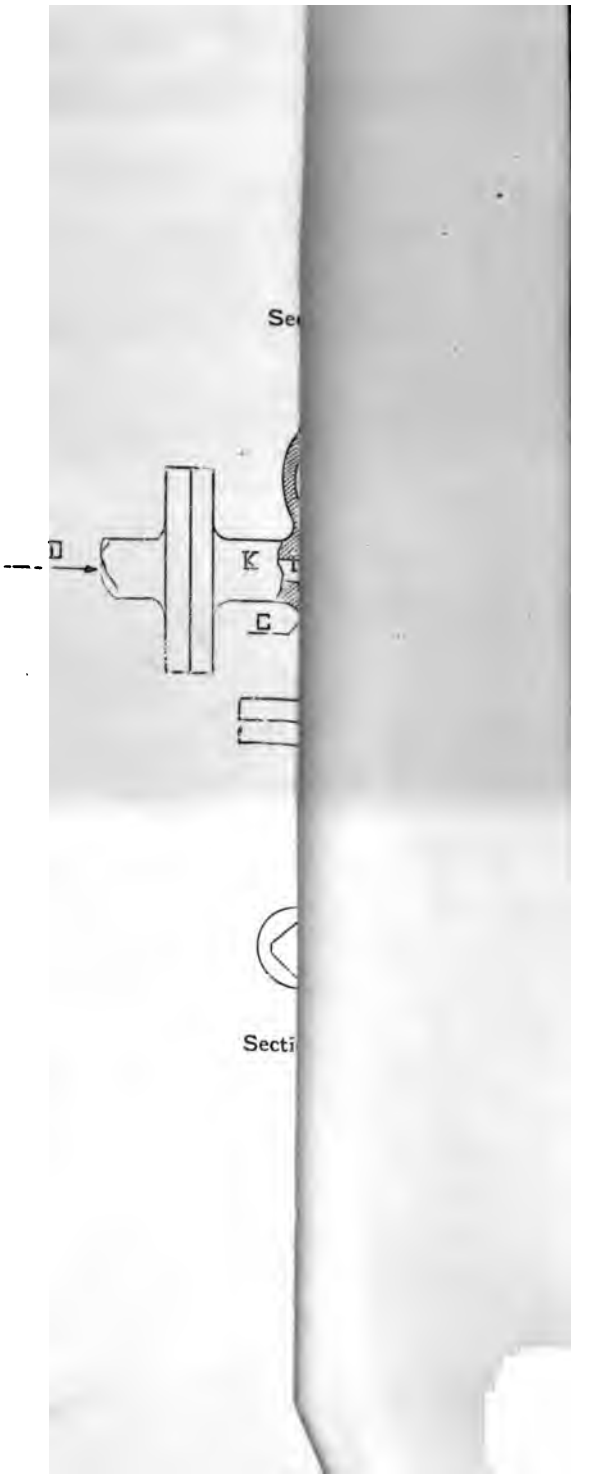

MUMFORD FEED-WATER REGULATOR
PIPE TO STEAM SPACE
LEVEL
LEVEL
LEVELLING PIPE TO WATER SPACE
WHEEL FOR ADJUSTING WORKING LEVEL

FIG. 156.




Se
K
C
Secti

Section on K
a
b

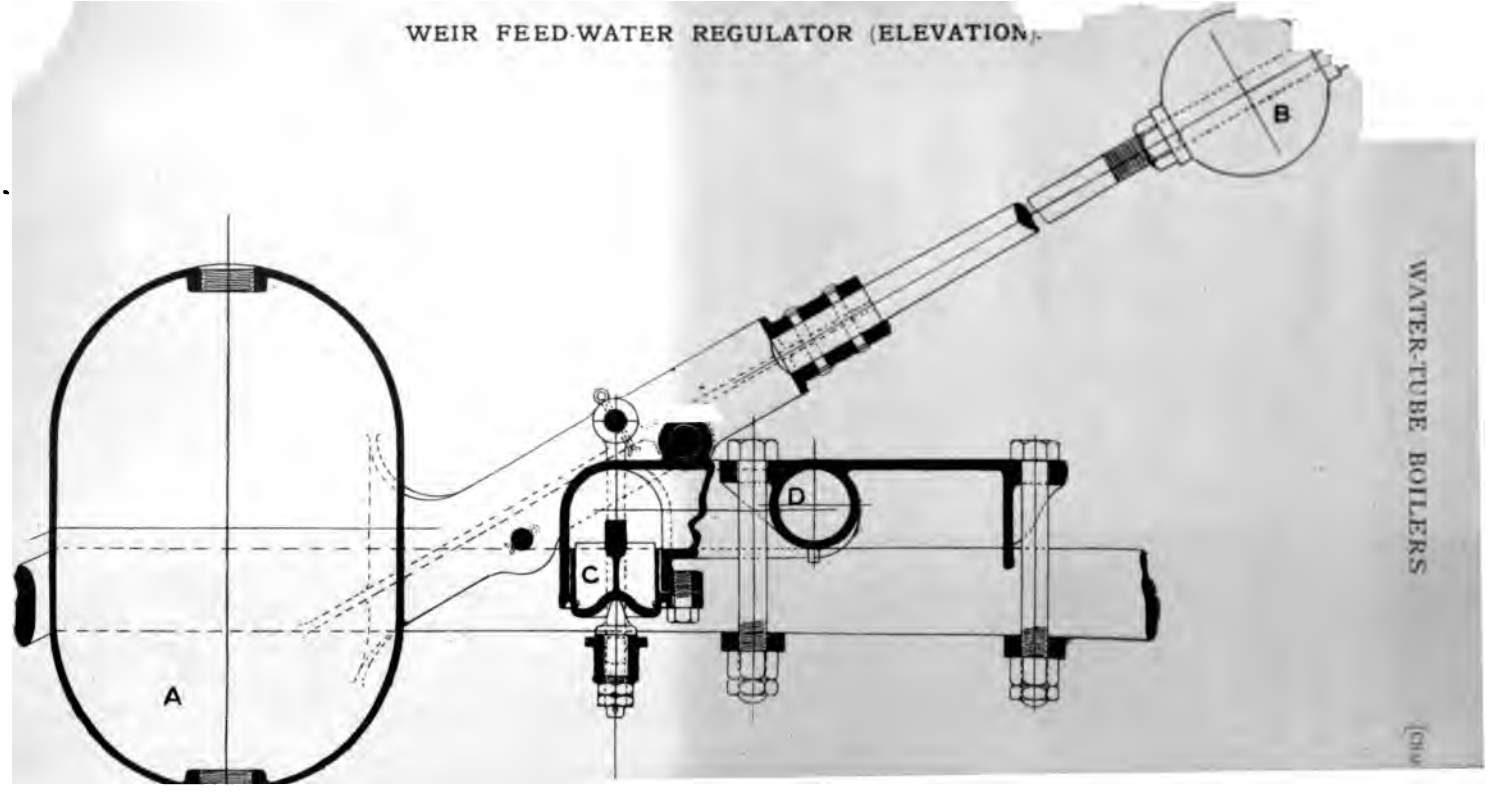
water-level rose in the top drum, it caused the end of an internal steam-pipe to dip below the water-level, and so send water to the feed-pumps instead of steam. This slowed down the feed-pumps and so allowed the water-level to drop. The arrangement has many obvious objections, was very uneconomical, and its use has since been discontinued.

57. Mumford Feed-Water Regulator.—The Mumford feed-water regulator (Fig. 156) is similar in many respects to those already described. It consists of a casting of an oblong shape, in which works a float, connected to a lever which works on a spindle passing through a stuffing box. To the float lever is attached, inside the casting, a spindle and valve, regulating the flow of the water from the feed-pump to the boiler. A hand-wheel is also attached to a continuation of the valve-spindle, for adjusting the working level. Outside the casting, a lever is attached to the spindle or rocking shaft above referred to; this lever is connected by means of a link to another lever carrying a counter-poise. The counter-poise weight is adjustable, and the whole arrangement can be worked by hand to see that the float and valve are free.

Though the regulator is able to keep the water level to within half-an-inch, it does not appear to be too sensitive for the rough usage it receives at sea.

58. Niclausse Feed-Regulator.—The Niclausse feed-water regulator (Figs. 157, 158) consists of an external casing A containing a balanced valve C, which is opened and closed by the action of a float B in the steam and water reservoir. The float, on rising or falling, rotates a spindle H, to the other end of which (inside the valve casing) is attached a short lever J, which connects by means of a link with the feed-valve.

WEIR FEED-WATER REGULATOR (ELEVATION).



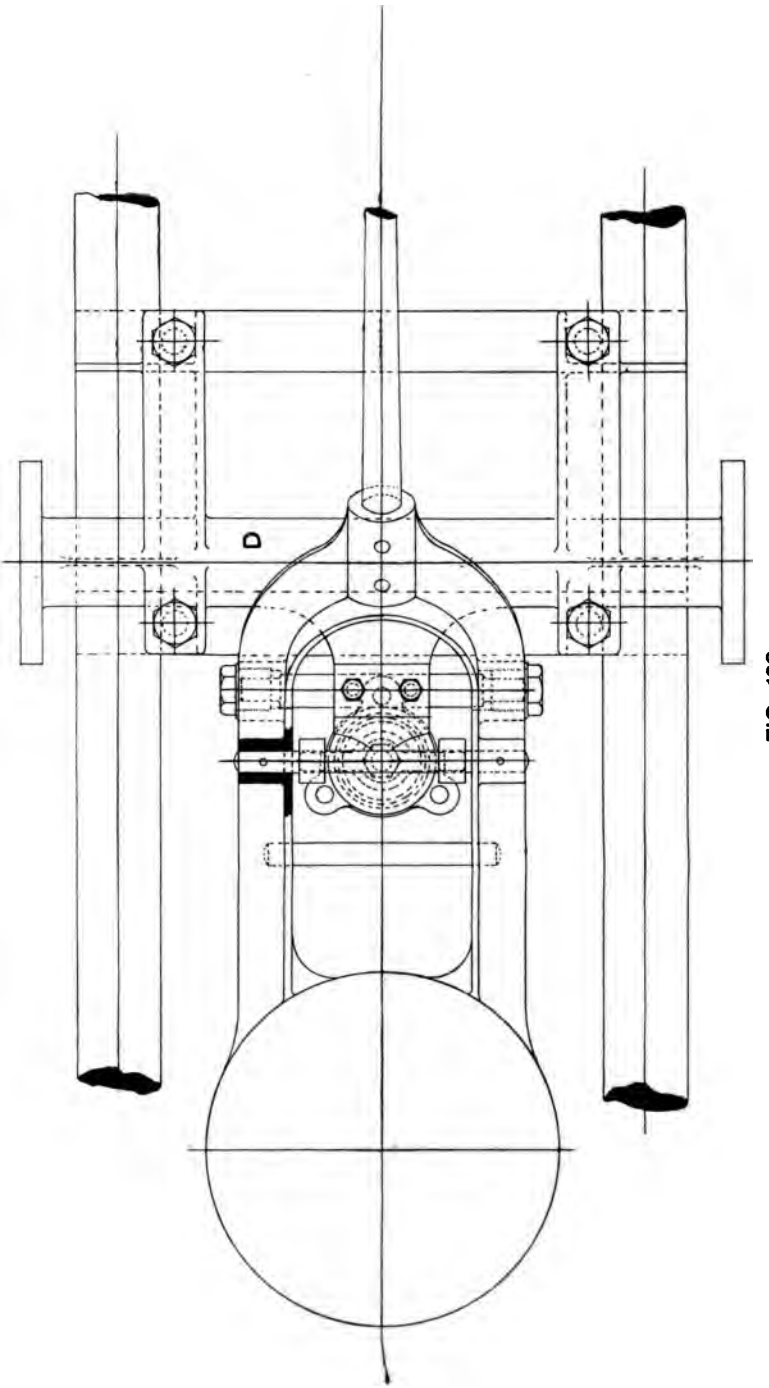


FIG. 160.

On the float rising, the spindle is rotated, and causes the short lever to press the valve on its seat, thus cutting off the supply of water to the boiler. On the float falling, the reverse action takes place and the valve opens. The spindle is not, however, continuous, but is made in two lengths H, H^1, which are coupled together, so that the position of the float can be altered relatively to the valve to suit different working levels. The float is balanced by a counterpoise, which is situated outside the boiler, and can be adjusted by hand.

59. Weir Feed-Water Regulator.—A feed-regulator or distributor (Figs. 159, 160) has been designed by Messrs. J. and G. Weir of Cathcart, Glasgow, to work in conjunction with their feed-pumps. It is situated within the boiler, and consists mainly of a float A and counterbalance B, actuating a disc-valve C, which closes against the inlet orifice as the float rises. As the pressure in the feed-range D acts directly on the face of the valve C, the greater the difference of pressure between the feed-range and the boiler, the greater the delivery. Also, the lower the water-level, the greater will be the opening of the valve for any given difference of pressure between the feed-range and the boiler: hence the total quantity of water delivered to any boiler will depend partly on the pressure existing in the boiler, and partly on the position of the water-level. In most of the types of feed-regulators, where a double-beat valve is used, the question of the pressure has next to no influence on the delivery, which is regulated entirely by the level of the water and the position of the float.

The apparatus has the merit of simplicity, but being entirely contained in the boiler, there is no means of ascertaining whether the float is free or not,

60. Feed-Pumps.—After what has been said about the great necessity for a regular feed, it will be readily understood that the feed-pump is a very important fitting, when tubulous boilers are used. Messrs Belleville make a special horizontal feed-pump of their own, which is used in conjunction with their boilers in foreign Navies, and in our own ships those of Messrs Weir are largely used. These latter are vertical direct acting pumps, and work with extreme steadiness and regularity. The space at our disposal is, however, too limited to attempt a description of these pumps, but they will be found very fully described in Sennett and Oram's work on the "Marine Steam-Engine." *

61. Necessity for Pure Feed-Water.—It has now come to be universally recognised that the purest feed-water obtainable must be used with tubulous boilers, if their circulation is to be maintained and their life not impaired. The introduction of sea-water as "make-up" always leads to trouble; so much so, that in one Navy, although rigid instructions were in force prohibiting the use of salt water, it was found necessary to blank-flange all the sea connections, and thereby absolutely preclude the possibility of any sea-water finding its way into the boilers. Sea-water has the effect of depositing its saline ingredients on the heating surfaces. If a tube becomes choked through any portion of its length, it reduces the rapidity of circulation throughout the rest of the tube; should further depositing take place, it may lead to the blocking of the tube and to its ultimate failure.

62. Filtering.—The question of filtering the feed water,

* "The Marine Steam Engine," R. Sennett and H. J. Oram. Longmans, Green & Co., 1898.

ıough it might appear a small matter at first, is, with bulous boilers, a matter of no mean importance. This not realized in the early days of water-tube boilers, was a fruitful source of many of the troubles that curred. Water coming from condensing engines always contains a certain amount of oil, and if this is allowed to pass into the boilers and accumulate on the heating surfaces, not only reduces their efficiency, but may eventually give e to overheating of the tubes, and their ultimate failure. Sir John Durston made some interesting experiments on the effect of grease in feed-water, which are alluded to on page 62.

The acids contained in the animal and vegetable oils sometimes used for lubrication are one of the principal agents in starting corrosion, and once corrosion is started, it gives rise to a local weakness, and renders the metal much more susceptible to further corrosion. When it is borne in mind that in tubulous boilers the tubes are usually comparatively thin, local pitting to the extent of $\frac{1}{32}$nd or, say, $\frac{1}{16}$th inch, forms a very large proportion of the total thickness of the tube, and the localisation of any pitting action must be attended with much more serious consequences than in the Scotch boiler, with its comparatively thick plates and tubes. For the reason, given on page 62, mineral oils have, where possible, taken the place of vegetable oils in lubrication.

At the high pressures and therefore higher temperatures now in vogue, the presence of oil in the feed-water becomes more dangerous. Mineral oil does not float for long on the water, but very soon deposits itself on the heating surfaces. When opening up some of the tubulous boilers after their trial trips in which a lot of oil has been used, some of which has found its way into the feed-water, a

brown deposit, more nearly resembling chocolate than anything else, has been found at the bottom of the water-drums.

There is no known practical chemical means of effectively depriving the feed-water of oil, and therefore mechanical means have to be resorted to.

There are two distinct systems of filters.

1. Those where the filtration takes place under full boiler pressure, which is the system in most general use in this country.

2. Those at which the filtration takes place at atmospheric pressure, principally used abroad.

The advantages of the first method are, that the filters are more compact, take up less room, and are more easily under control; but the disadvantages are, that it adds to the number of vessels subjected to the full boiler pressure, it increases the load on the feed-pumps, and the pulsating action of the feed-pump might tend to dislodge some of the oil from the filtering medium.

The second method where the filtration takes place at atmospheric pressure, between the delivery side of the air-pump and suction side of the feed-pump, avoids any interference with the main feed-range, and allows more volume for the filtration, but has the disadvantage of occupying a greater space, and making the supply of feed-water to the feed-pumps more irregular.

63. Harris Filter.—Harris's filter (Fig. 161) consists of a casing containing a number of circular gratings placed one upon the other. Between each grating is placed a layer of filtering material supported by wire gauze. The gratings are so arranged that there is a large central chamber for the entrance of the feed-water, which passes into, and finds

its way out at the circumference of this chamber, through holes in the gratings, into the spaces between the layers of filtering material. After passing through the filtering

HARRIS FEED-WATER FILTER.

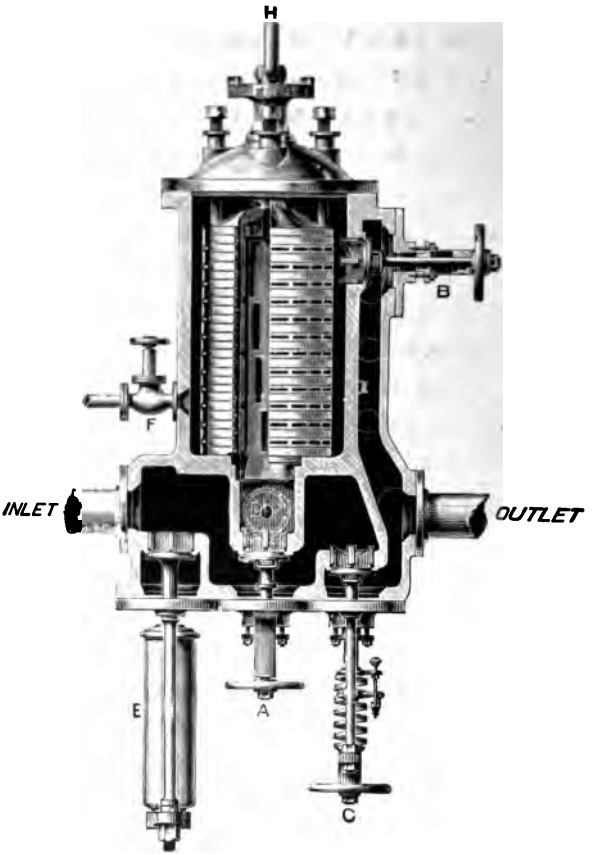


FIG. 161.

material, it makes its exit through similar holes in the circumference, and out at the top of the filter.

64. Rankine Feed-Water Filter. — Rankine's patent feed-water filter (Fig. 162) consists of a series of cylindrical

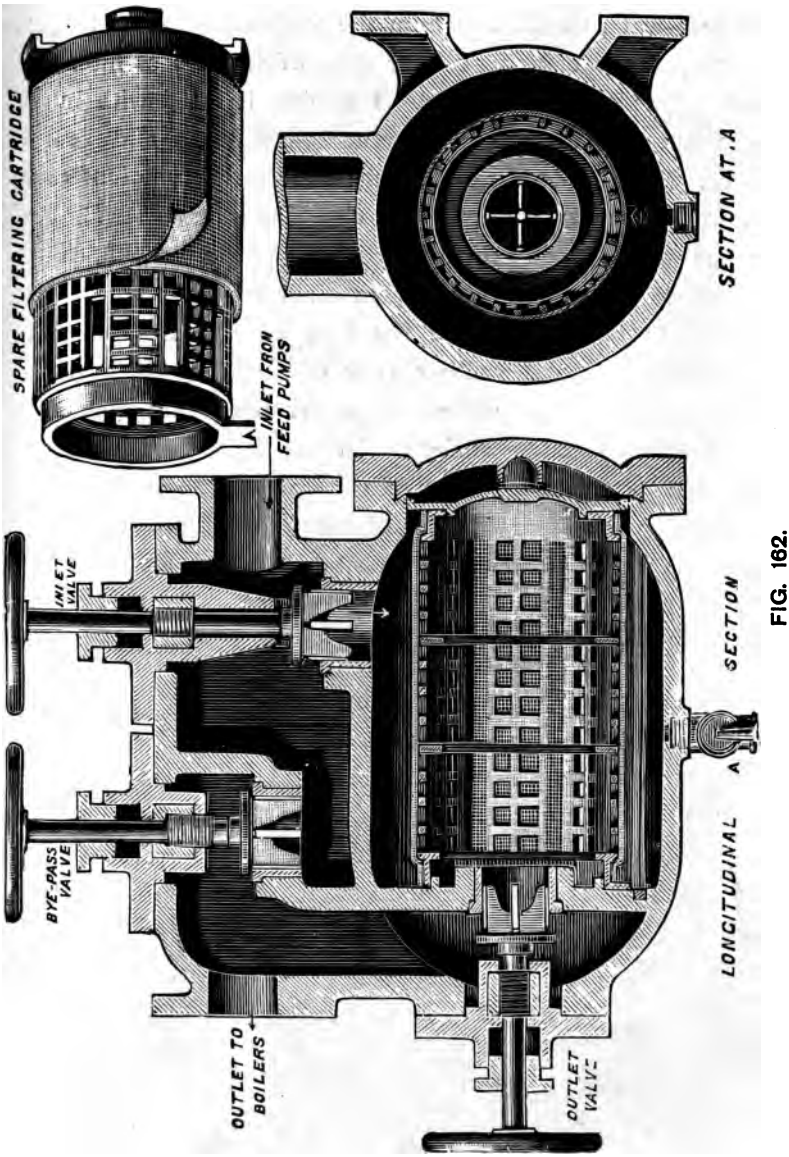

SPARE FILTERING CARTRIDGE
INLET FROM FEED PUMPS
SECTION AT A
INLET VALVE
BYE-PASS VALVE
OUTLET TO BOILERS
OUTLET VALVE
LONGITUDINAL SECTION

FIG. 162.

gratings, over which the filtering medium is stretched, and the feed-water on its way from the feed-pump to the boiler has to pass through one, two, or three thicknesses of filtering material, as the case may be. The filter is fitted with bye-pass, cut-out valves, etc., together with steam and drain cocks. The frame-work carrying the filtering medium can be very easily withdrawn for cleansing and renewal, by means of the door provided for that purpose. Sufficient allowance of area of filtering medium must be made, so as not to unduly increase the load on the feed-pumps; this is done in the multiple type of filter, by substituting for one cartridge a number of smaller ones, thus giving a considerable filtering surface. In the Admiralty type of multiple filter, there are three separate chambers, each containing the same number of cartridges, and having the same filtering area, and the feed-water passes through each chamber in succession.

65. Mills-Berryman Feed-Water Filter.—The Mills-Berryman "Sentry" filter, made by Messrs Storey (Figs. 163, 164), is extremely simple in construction, and consists roughly of an outer casting, in which is enclosed a perforated basket filled with filtering medium. The water first passes through the fibrous material (which is generally wood wool) where the greater portion of the oil and any solid matter is retained, and then passes through one or two thicknesses of filtering cloth. The velocity through the cloth is nominally 6″ per minute. The perforated basket can be readily removed and another one substituted ready packed for use. The usual valves, bye-pass, pressure-gauge, drain-cock, etc., are fitted.

66. Filters Working at Atmospheric Pressure—Normand Filter.—The filter used almost exclusively till

recently in the French Navy is that introduced by M. Normand (Fig 165), which consists roughly of placing in the hot well or between the hot well and the discharge side of the air-pumps three layers of sponges. The water on its passage

MILLS-BERRYMAN FEED-WATER FILTER.

FIG. 163.

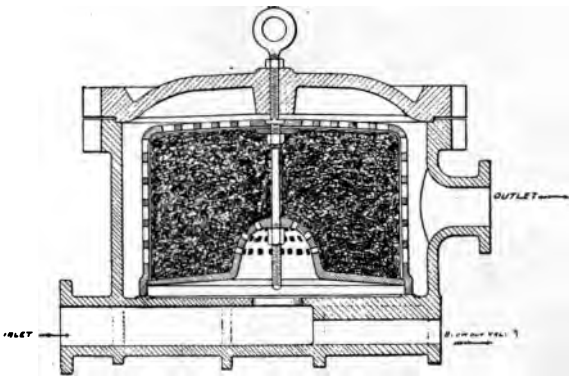


FIG. 164.

through these is deprived of the oil held in suspension. These filters, though satisfactory in some ways, are bulky, and do not completely extract the very fine particles of oil contained in the form of an emulsion in the feed-water, and the sponges are expensive to renew.

The great benefit of using filters is that the oil contained

in the feed-water is deposited in the filters from whence it is easily removed, and where it is not subjected to high temperatures, instead of being deposited on the boiler surfaces where the temperature is very high, and from whence it cannot easily be removed.

NORMAND FEED-WATER FILTER.

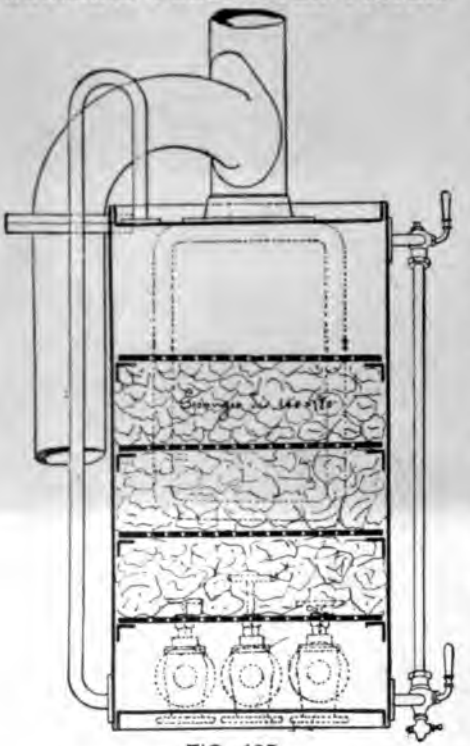


FIG. 165.

67. Feed-Water Heaters. — The advantages of heating the feed-water are two-fold :—

1. It somewhat reduces the amount of work to be done by the boiler which, in all cases where tubulous boilers are fitted, is the weaker link in the machinery chain.

2. The water on its introduction into the boiler when hot is in a better position to take up the heat from the gases than if it had been introduced cold.

There is a certain distinct advantage to be gained, due to the fact that the heated feed-water introduces with it a certain number of thermal units into the boiler, and liberates a certain amount of heat (which would otherwise be employed in heating the cold feed-water) to perform the more useful work of converting the water into steam. This ad-

vantage is, however, small compared with that which is due to raising the total mean temperature of the water in the boiler.

The quicker the water is turned into steam the more rapid will be the circulation; the more rapid the circulation, the greater will be the heat-absorbing power of the heating surface. Experiments on this subject show that the co-efficient of transmission of a given surface varies from 1 to 5 as the water in contact with the surface approaches the boiling point or is actually boiling.

There are two methods of heating the feed-water:—

1. By mean of the waste gases.
2. By means of live and exhaust steam.

We will deal with the method of heating the feed-water by means of the waste gases first.

Numerous attempts have been made to use the waste gases for heating the feed-water. M. Belleville, as we saw, used this form of heater in his earliest type of boiler in 1855 (Fig 12). It was not then successful, and its use had to be discontinued. It was subsequently re-introduced in the form of the present economizer, and the Boiler Commission have now recommended that its use should again be discontinued.* There are inseparable difficulties attending this system of feed-heating, principally that of the corrosion of the tubes, and in all the various systems which have at one time or the other been tried on board ship, this same difficulty has ultimately led to their discontinuance. On land, however, the use of the escaping gases as a heating agent has been more successful, due to the somewhat different conditions surrounding their use, facilities for cleaning, inspection, and so forth. The well-known Green's Economiser and others of this type are examples of the success that has attended this class of heater on shore.

* Appendix, p. 199.

second method, that is to say steam-heating, is really only satisfactory method of heating the feed-water at whether it be by direct steam, as used by Messrs aldy, or by steam from the receivers of the engines, as by Messrs Weir or M. Normand, or whether it be by haust steam from auxiliary engines, as is now being ployed in the Navy.

ed-heaters using steam as a heating-agent may roughly ided into two classes.

1. Surface heaters.
2. Injection heaters.

As typical of the first class, we may cite the heaters of Messrs Kirkaldy and M. Normand.

KIRKALDY HEATER.

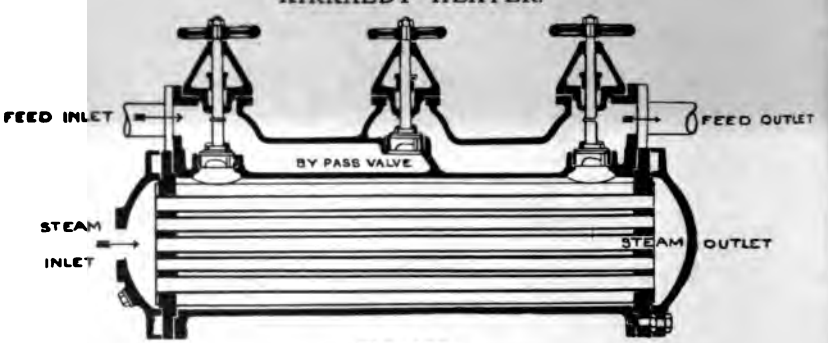


FIG. 166.

68. Kirkaldy Heater.—Messrs Kirkaldy's heater (Fig. 166) consists of a casing in which are placed a number of straight horizontal tubes, expanded into a tube plate at either end. The steam passes through the tubes, while the water to be heated is on the outside.

69. Normand Heater.—M. Normand's heater (Figs. 167, 168) is the converse of this; it consists of a thin copper casing

NORMAND FEED-WATER HEATER.

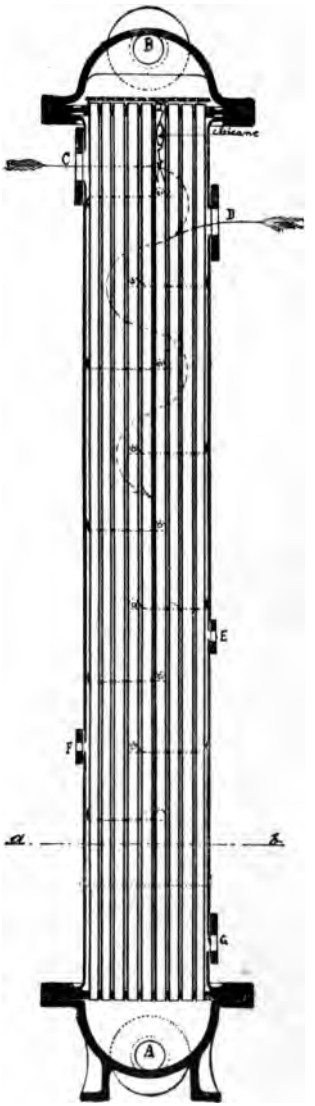
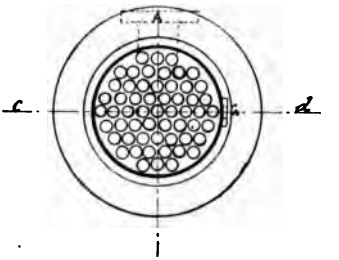


FIG. 167.



Section on A B, Fig. 167.

FIG. 168.

WAINWRIGHT HEATER.

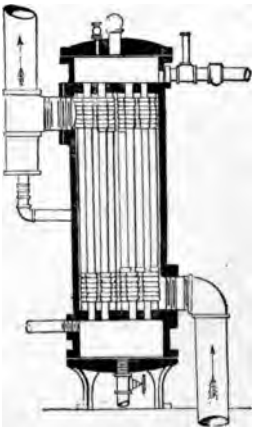


FIG. 169.

rounding a nest of straight vertical tubes, which are ex-
tube plate at either end. The exhaust steam
ater at C or D, passing in among the nest of
the feed-water enters at A, passes through the
out at B. Baffles are fitted so as to distribute the
roughly among the tubes, baffles also being fitted
ne inside of the tubes to ensure all the particles of water
in frequent contact with the heated sides of the tubes.
condensed steam and water is taken away at G by an
automatic trap. Steam is taken from the L.P. casing, and
enters the heater at C, or from the exhaust of the auxiliary
ngine, entering the heater at D.

The heater is extremely efficient on a very small weight.

The Wainwright heater (Fig. 159) is a surface-heater of American design on somewhat similar lines to M. Normand's.

70. Weir Surface Heater.—Weir's Surface Heater (Fig. 170) consists of an outside shell of gun-metal or cast-iron, containing a nest of straight vertical tubes fixed in two plates at either side. The steam enters the top of the heater and passes through the tubes, the condensed steam being taken off by a drain at the bottom. The feed-water enters at the bottom of the heater, passes round the outsides of the tubes, and out at the top of the heater.

71. Injection Heaters.—Injection heaters are principally used in the Mercantile Marine, as the head required for ensuring the satisfactory working of the feed-pumps would bring the heaters above the armoured deck, and so precludes their use in the Navy.

Messrs Weir's injection heater (Fig. 171) consists of a circular vessel, in which the cold feed-water is sprayed in at the top, falls through the steam coming from the L.P. casing,

WEIR FEED-WATER HEATER.

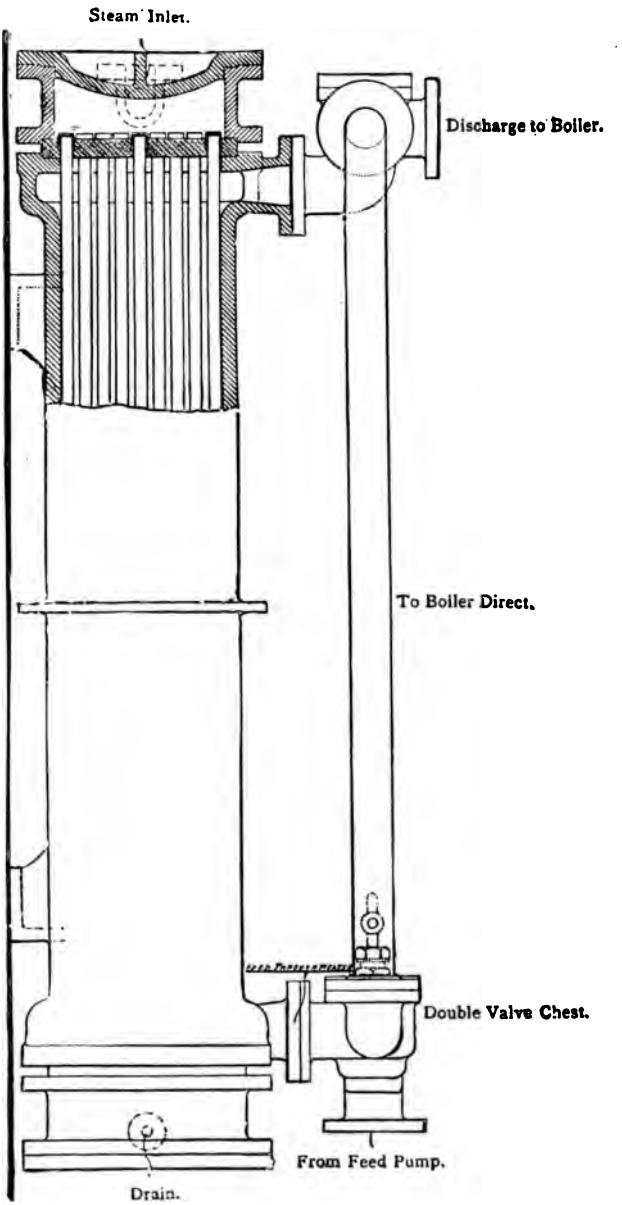


FIG. 170.

and becomes heated and falls to the bottom of the heater. The bottom of the heater is fitted with a float which regulates the supply of steam to the feed-pumps, and controls the quantity of feed-water passing to the boiler.

WEIR INJECTION HEATER.

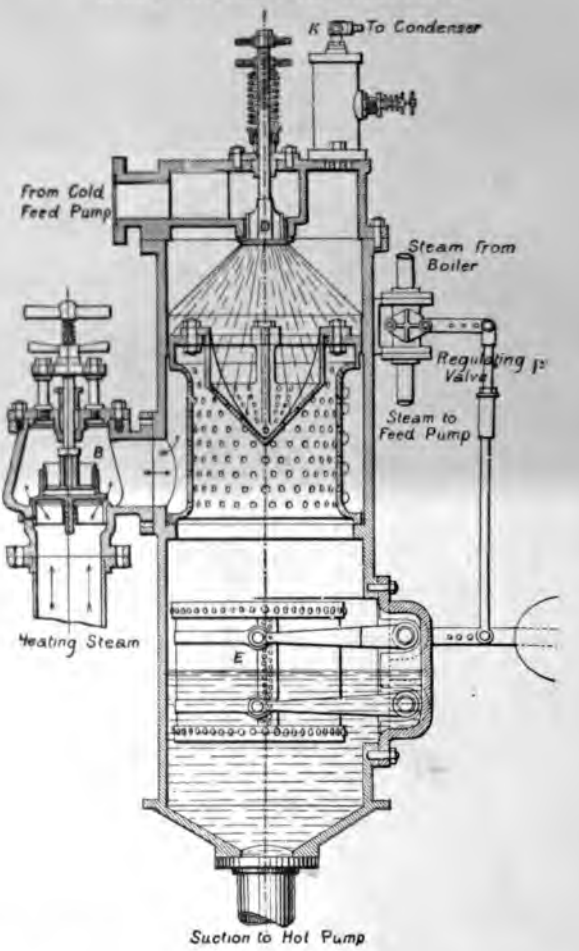


FIG. 171.

72. **Weight and Space occupied by Various Types of Boilers.**—The question of the saving of weight is most

important, and has been one of the chief factors in the introduction of the water-tube boiler. The saving may be said to be due to two causes:—

1. The very much smaller volume of water contained in the boiler.

2. The reduced thickness of the water receptacles (tubes, etc.) due to their smaller diameter.

The amount of water in a water-tube boiler is about 5 lbs. per I.H.P. The amount of water usually present in a Marine-type boiler is about 44 lbs. per I.H.P., and in the locomotive-type 11 lbs. per I.H.P.

These figures are of course only approximate, but it will be seen that the water-tube boiler has a considerable advantage as regards weight of water over the Scotch boiler. There is, however, a disadvantage in making the contained volume of water small, to which we shall refer later.

With regard to the saving due to weight. A very considerable amount of this is due to the fact that in the ordinary cylindrical boiler the shell has to be made, not only to contain the steam and water, but also to enclose the furnace and passages for the gases.

In the following table the average weights of some tubulous boilers are given, and also those for locomotive and Admiralty-type boilers. The Admiralty-type boiler differs from the Marine-type, in that the tubes are placed as a continuation of the furnace, the combustion chamber being between the furnace and tubes, and consequently the hot gases do not return to the front of the boiler as in the Marine-type. This type of boiler was introduced into the Navy on account of the limited head-room available on a man-of-war, and this arrangement of the tubes reduces the diameter of the boiler. The boiler-room weights for the water-tube boilers, with the exception of those for the Babcock and

ox- ausse, d'Allest, and Oriolle boilers, are based
s of some official trials given in the paper by
rston and Mr Oram, before the Institution of
ers in 1899;* those for the cylindrical boilers
m p r by Sir John Durston, read in 1894.† With
exception of the Babcock and Wilcox boiler, the
naining weights and the vertical projections are taken
m the figures given by the Chief Constructor of the
nch Navy in his work on "Marine Boilers."

The horizontal space required by a boiler may be expressed by the ratio of the surface formed by the vertical projection of its horizontal dim sions to the vertical projection of its grate area. been done where possible, and the results given in g table:—

Name of Boiler.		Vertical Projection of Boiler.	Vertical Projection of Grate.	Ratio.
Thornycroft . . .		105.8	38.04	2.8
Reed	35	—	—	—
Normand . . .	30	122.5	41.4	3.4
Yarrow	34	—	—	—
Blechynden . . .	32	—	—	—
White	38	—	—	—
Belleville (without Economiser) . . .	100	65.14	40.4	1.6
Belleville (with Economiser)	98			
Babcock & Wilcox . .	69	—	—	—
Niclausse . . .	86	155.4	102.4	1.5
D'Allest	88	126.4	64.3	2.0
Oriolle	42	48.1	27.8	1.7
Locomotive-type . .	70	—	—	—
Admiralty-type . .	119	189.7	60.3	3.1
Single-ended Return-tube (Naval) . . .	119	121.7	58.7	2.1
Double-ended Return-tube (Naval) . . .	91	275.7	156.8	1.8

* Minutes of Proceedings, Inst.C.E., vol. cxxxvii.
† Minutes of Proceedings, Inst.C.E., vol. cxix.

73. Advantages.—Most things have good and bad points, and tubulous boilers are no exception to the rule, and the question as to whether their merits outweigh those of cylindrical boilers, or *vice versa*, depends entirely on the requirements of the particular service for which they are intended.

To deal first with the *advantages* of tubulous boilers. Tubulous boilers are particularly well adapted for generating steam at a very high pressure, because the majority of them are composed of cylindrical elements of small diameter, the pressure in all cases being internal. In the ordinary cylindrical boiler a maximum pressure is soon reached, which, as regards the shell, is strictly limited by the thickness of shell plates obtainable, and for the furnace, by difficulties in construction which have not as yet been overcome. In the tubulous boiler, on the contrary, no limit of pressure is imposed, except by considerations effecting the working of the engines. Tubulous boilers are now commonly made for a working pressure of 300 lbs. per square inch, a reducing valve supplying steam to the engines at a pressure of 260 lbs. per square inch. To quote recent practice, Mosher in America is at present engaged in fitting a steam yacht with his type of boiler, in which the pressure was originally designed to be 440 lbs. per square inch, the steam pressure being reduced at the engines to 400 lbs. per square inch, but the boat is not yet completed.

Another advantage claimed for the tubulous boiler is the comparative immunity from accidents of a serious nature. This depends partly upon the ability of the boiler to withstand very much higher pressures than the working pressure, and partly on the small volume of water and steam contained in the boiler. Except in their immediate surroundings, tubulous boilers are undoubtedly a far less dangerous

about adjacent structures than tubular or cylindrical boilers, as the effect of an explosion is felt over a much larger area. This is of particular importance in the case of damage to a boiler by shot or shell fire, as the result would not be so disastrous as in the case of the ordinary cylindrical boiler.

The Thornycroft and du Temple boilers have had the inner tubes next to the furnace severely burnt, owing to shortness of water, without any injury to the stokers. It is, however, impossible to state that the stokehold staff incur no risk in the event of an explosion of a water-tube boiler, but the consequences are not so grave as those that would have resulted from a similar accident to boilers of the locomotive- or marine-type.

Tubulous boilers have a material advantage over the marine-type of boiler for naval purposes, as they stand forcing much better. This is especially true of boilers of the small-tube type. The tubes are more easily kept cool and much less subjected to the action of heat, and there are no furnaces to bulge or collapse, and as a rule the boilers are able to expand, and contract more freely. In consequence of this freedom to expand, steam can be raised rapidly in an emergency, or the boiler can be cooled rapidly for the purpose of carrying out small repairs or cleaning, without developing leaky tube joints. The *Sharpshooter*, fitted with Belleville boilers, raised steam from cold water in twenty minutes from the time of lighting the fires.

Yet another point in favour of tubulous boilers for naval purposes is that the number of boilers at work is increased, and, in consequence, the failure of any one of them deprives the ship of a much smaller proportion of her total power than would be the case if fewer and more powerful boilers were fitted.

A further point in connection with many water-tube boilers which is in their favour is that being built in sections a completely new section can be fitted to the boiler in a very short time, and also the re-boilering of a ship does not involve opening up the decks, as the boiler can be sent down piecemeal.

74. Disadvantages.—With the undeniable advantages of tubulous boilers, it must be confessed there are also certain disadvantages. These may be stated as follows:—

On account of the small amount of water they contain, tubulous boilers require most careful attention to the feed-water, as a short interruption in the feed supply will make a considerable alteration in the water-level. As an instance, take the case of a boiler of 55 square feet of grate, working under forced draught and evaporating 12 tons of water per hour. If the steam and water drum up to the working level contains one ton of water, an interruption of the feed supply would empty it in five minutes; the fall of level in the tubes would then be extremely rapid. The top drum is not as a rule in contact with the hot gases, but the tubes are subject to temperatures capable of fusing the steel. The maintenance of the water-level and the management of the feed requires therefore very careful attention. In large ships where several boilers are fed from a common feed-pipe, the adoption of automatic feed-regulators used generally to be regarded as an absolute necessity, but recently the tendency has been to dispense with them.

It is strictly necessary that the water for feeding tubulous boilers should be absolutely pure. The tubes can only withstand the intense heat when cooled by a constant current of water. Any tube in which deposit has commenced to form will soon become obstructed, as deposits

tend to increase, due to retardation of the circulation, and an obstructed tube means a burnt tube. The use of sea-water must be rigorously avoided, and the fittings used to purify the feed-water must be kept in full working order.

The disadvantages of tubulous boilers lie mainly in the danger that may result from their breaking down, but this can be minimised by incessant and careful inspection.

75. Durability.—As regards the comparative durability of water-tube and cylindrical boilers, it is impossible to state conclusions on this point with certainty, as experience with water-tube boilers has so far been limited. It is largely a matter of treatment, and it must be remembered that the present long life of cylindrical boilers is the result of years of experience in their management. At one time eight years was looked upon as an excellent result, and now twenty years' service is by no means uncommon in the Merchant service.* In the case of one of the White Star Liners, the original boilers were still being worked after twenty-four years' service.

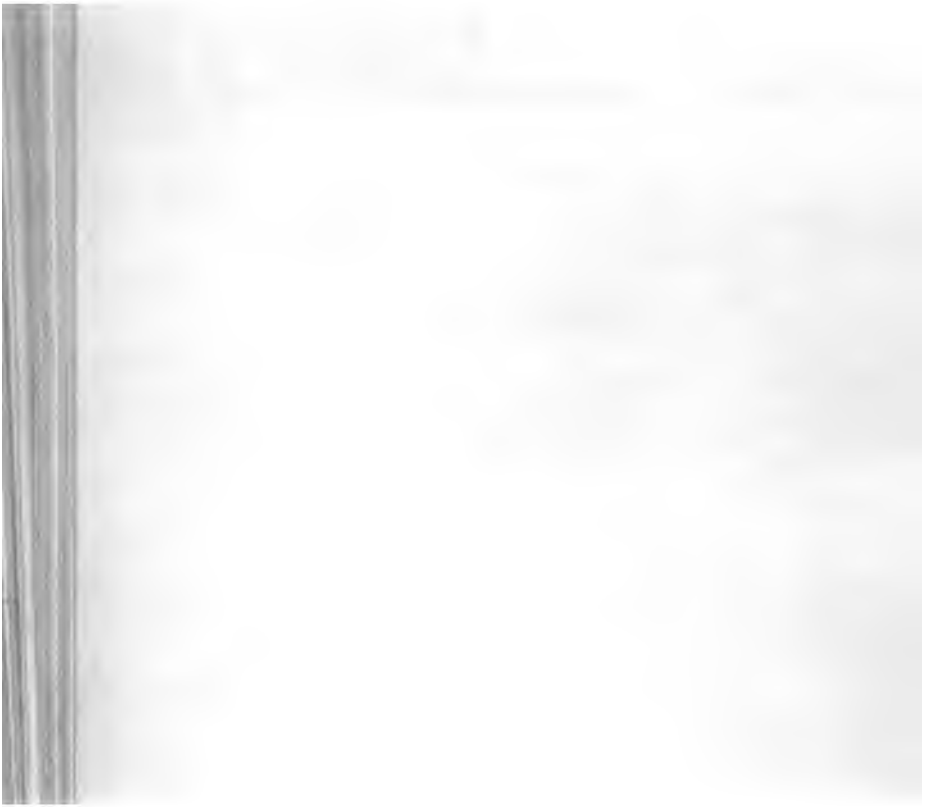
As our acquaintance with water-tube boilers grows, there seems to be no reason why, in the Navy at least, the water-tube boiler should not be equal in durability to the cylindrical boiler.

76. General Conclusions.—In the interim report of the

* This is, however, only true for the Merchant service. M. Bertin, the Chief Constructor of the French Navy, in his work on "Marine Boilers," gives eight, or at most, ten years, as the life of cylindrical boilers in warships, including one complete overhauling during that period. He concludes with these words: "On the other hand, when the conditions are altogether against durability, as on torpedo-boats, where locomotive boilers only last three years, tubulous boilers offer a decided advantage; Mr Thornycroft states that his boilers usually stand eight years' service without extensive repairs, certainly without a thorough over-hauling." "Marine Boilers," Bertin (English Edition), John Murray.

Boiler Committee, which has recently been presented to Parliament, the Committee state "that the advantages of water-tube boilers for Naval purposes are so great, chiefly from a military point of view, that, provided a satisfactory type of water-tube boiler be adopted, it would be more suitable for use in His Majesty's Navy than the cylindrical-type boiler."

This opinion endorses those of the Naval advisers of practically all the great sea powers. Rear-Admiral Melville, the Engineer-in-Chief of the United States Navy, has expressed his opinion that "if the battle of Santiago taught nothing else, it certainly made very clear the absolute necessity of water-tube boilers on our modern war-vessels."



APPENDIX

INTERIM REPORT OF THE COMMITTEE, APPOINTED BY THE LORDS COMMISSIONERS OF THE ADMIRALTY, TO CONSIDER CERTAIN QUESTIONS RESPECTING MODERN TYPES OF BOILERS FOR NAVAL PURPOSES.

COPY OF THE LETTER OF INSTRUCTIONS SENT TO THE PRESIDENT.

S. 17864—18248.

ADMIRALTY, S.W.,
6th September 1900.

SIR,—I am commanded by my Lords Commissioners of the Admiralty to inform you that they are pleased to nominate you as Chairman of a Committee which they have decided to appoint for the purpose of considering certain questions arising in connection with the use of various modern types of boilers for naval purposes, as set forth in the terms of reference specified in the succeeding paragraphs of this letter.

(2.) In addition to yourself, the Committee will be composed of the following members:—

Mr J. A. Smith (Inspector of Machinery, R.N.).

Mr John List, R.N.R. (Superintending Engineer, "Castle" Line).

Mr James Bain, R.N.R. (Superintending Engineer "Cunard" Line).

Mr J. T. Milton (Chief Engineer-Surveyor of Lloyd's Register of Shipping).

Professor A. B. W. Kennedy.

Mr J. Inglis, LL.D. (Head of the firm of Messrs. A. & J. Inglis, Engineers and Shipbuilders, Pointhouse, Glasgow).

Commander Montague E. Browning, R.N., and Chief Engineer William H. Wood, R.N., will act as Joint Secretaries to the Committee.

(3.) The points which it is desired that the Committee should investigate and report upon are as follows:—

(*a.*) To ascertain practically and experimentally the relative advantages and disadvantages of the Belleville boiler for naval purposes as compared with the cylindrical boiler.

(*b.*) To investigate the causes of the defects which have occurred in these boilers and in the machinery of ships fitted with them, and to report how far they are preventable either by modifications of details or by difference of treatment, and how far they are inherent in the system. The Committee should also report generally on the suitability of the propelling and auxiliary machinery fitted in recent war vessels, and offer any suggestions for improvement, the effect as regards weight and space of any alterations proposed being stated.

(*c.*) To report on the advantages and disadvantages of the Niclausse and Babcock and Wilcox boilers compared with the Belleville as far as the means at the disposal of the Committee permit, and also to report whether any other description of boiler has sufficient advantages over the Belleville or the other two types above mentioned as a boiler for large cruisers and battleships to make it advisable to fit it in any of Her Majesty's ships for trial.

(4.) For the purpose of making direct experiments between ships fitted with Belleville and cylindrical boilers respectively, the *Hyacinth*, fitted with Belleville boilers, will be placed at the disposal of the Committee as soon as the crew have been sufficiently trained and such trials have been carried out as to ensure that the machinery is in efficient order. A cruiser of similar type fitted with cylindrical boilers will also be placed at the disposal of the Committee when required, for the purposes of comparison.

(5.) For the investigation of defects, copies of the reports of all the defects of machinery and boilers which occurred during the recent naval manœuvres will be placed before the Committtee, and they will be able to inspect ships specially commissioned for the manœuvres, which include the *Ariadne* and *Gladiator* with Belleville boilers and the *Perseus* and *Prometheus* with Thornycroft boilers, with any others that may have returned to any of the home ports.

(6.) The *Europa* is now on passage from Australia, and it is desired that, at a suitable time, an investigation into the causes of her high coal expenditure and machinery defects shall be conducted

under the directions of the Committee, and that she shall afterwards be put through such trials as the Committee think necessary.

(7). Information on any special points connected with the behaviour of the boilers or machinery of water-tube boiler ships on ordinary peace service which the Committee may desire to have will be obtained by the Admiralty from any of Her Majesty's ships in commission, and opportunities can be taken when the Channel Squadron is in any of the home ports to examine the boilers and machinery of the *Niobe*, *Diadem*, *Arrogant*, and *Furious*, which have Belleville boilers, and the *Pactolus*, which is fitted with Blechynden boilers.

(8.) The *Pelorus*, fitted with Normand boilers, which has recently returned from three years' continuous service in the Channel Squadron and at the Cape of Good Hope, and the *Powerful*, will also be available for examination during their refits.

(9.) The *Sharpshooter*, fitted with Belleville boilers without economisers, the *Seagull*, fitted with Niclausse, and the *Sheldrake* with Babcock and Wilcox boilers, will be employed in training stokers, and will be available for examination, and, if necessary, for any comparative experiments between these boilers that the Committee may wish to make, though the comparatively low pressure for which the machinery of these vessels was designed makes it impossible to try these boilers under the conditions under which they would work if fitted in a new ship.

(10.) It is particularly desired that any conclusions the Committee may arrive at should be supported by experimental proof as far as possible, and that the Committee should propose any further experiments they think necessary for this purpose.—I am, Sir, your obedient servant,

EVAN MACGREGOR,
Secretary.

Vice-Admiral Sir COMPTON DOMVILE, K.C.B.

COPY OF LETTER ASKING FOR AN INTERIM REPORT

S. 315—407.

ADMIRALTY, S.W.,
4th January 1901.

SIR,—I am commanded by my Lords Commissioners of the Admiralty to inform you that they will be glad to have an interim report from the Boiler Committee, as soon as possible, on any of the points referred to the Committee on which they consider they have collected sufficient evidence or experimental proof to enable them to form a reliable opinion.

The questions to which my Lords especially desire an answer, are the following:—

(1.) With the experience and information which have already been obtained, can it be stated whether water-tube boilers are considered by the Committee to be more suitable than cylindrical boilers for naval purposes?

(2.) Should the answer to the above question be in the affirmative, do the Committee consider that the Belleville boiler has such an advantage over other types of water-tube boilers as to lead them to recommend it as that best adapted to the requirement of H.M. Navy?

(3.) Generally, having regard to the importance of deciding on the types of boilers to be provided for vessels which are ordered in the immediate future, are the Committee prepared at present to make any recommendation, or to offer any suggestions on the extent to which any particular type or types of boilers should be fitted in new vessels?

Whilst their Lordships are anxious to receive an interim report at as early a date as practicable, they in no way wish to press the Committee for a premature expression of opinion.

I may add that any report made should be accompanied by full particulars of all the evidence and experimental data on which the recommendations of the Committee are based.—I am, Sir, your obedient servant,

EVAN MACGREGOR.

The Secretary,
Boiler Committee.

ADMIRALTY,
19th February 1901.

BOILER COMMITTEE.

SIR,—I have now the [illegible] submit for their Lordships' information the *ad interim* [illegible] called for by their letter S. 315/407 of the 4th January 1901 on the three questions to which the attention of the Committee was especially directed, viz. :—

"(1.) With the experience and information which have already been obtained, can it be stated whether water-tube boilers are considered by the Committee to be more suitable than cylindrical boilers for naval purposes?

"(2.) Should the answer to the above question be in the affirmative, do the Committee consider that the Belleville boiler has such an advantage over other types of water-tube boilers as to lead them to recommend it as that best adapted to the requirement of H.M. Navy?

"(3.) Generally, having regard to the importance of deciding on the types of boilers to be provided for vessels which are ordered in the immediate future, are the Committee prepared at present to make any recommendations or to offer any suggestions on the extent to which any particular type or types of boilers should be fitted in new vessels?"

The replies to these questions are given in the first three paragraphs of the Report, and the reasons for the replies in the remaining paragraphs, with all the advice the Committee are at present able to

give on the subject of the future boiler for the navy, with suggestions for trying two new types of boiler as quickly as possible.

The Report is unanimous with the exception of Mr J. A. Smith, Inspector of Machinery, who, though agreeing with the tenor of the Report as a whole, explains that, in his opinion, the Belleville boiler will give satisfactory results when carefully treated, and considers there is no necessity for delaying the progress of ships already designed for them.

In conclusion, I should like to bring to their Lordships' notice the great zeal and trouble taken by the civilian members of this Committee to attend the meetings and trials necessary to form an opinion on this question, often at great inconvenience to themselves, being all busy men with their own special work to do.—I have the honour to be, Sir, your obedient servant,

COMPTON DOMVILE, Vice-Admiral,
President, Boiler Committee.

The Secretary
of the Admiralty.

AD INTERIM REPORT.

(1.) The Committee are of opinion that the advantages of water-tube boilers for naval purposes are so great, chiefly from the military point of view, that, provided a satisfactory type of water-tube boiler be adopted, it would be more suitable for use in His Majesty's Navy than the cylindrical type of boiler.

(2.) The Committee do not consider that the Belleville boiler has any such advantage over other types of water-tube boilers as to lead them to recommend it as the best adapted to the requirements of His Majesty's Navy.

(3.) The Committee recommend:—

(*a.*) As regards ships which are to be ordered in the future:—That Belleville boilers be not fitted in any case.

(*b.*) As regards ships recently ordered, for which the work done on the boilers is not too far advanced:—That Belleville boilers be not fitted.

(*c.*) As regards ships under construction, for which the work is so far advanced that any alteration of type of boiler would delay the completion of the ships:—That Belleville boilers be retained.

(*d.*) As regards completed ships:—That Belleville boilers be retained as fitted.

(4.) In addition to the Belleville type of boiler, the Committee have had under consideration four types of large straight tube boilers which have been tried in war vessels, and are now being adopted on an extended scale in foreign Navies. These are:—

(*a.*) The Babcock and Wilcox boiler.

(*b.*) The Niclausse boiler.

(*c.*) The Dürr boiler.

(*d.*) The Yarrow large-tube boiler.

(*a*) and (*b*) have also been tried in our own Navy with satisfactory results, and are now being adopted on a limited scale.

If a type of water-tube boiler has to be decided on at once for use in the Navy, the Committee suggest that some or all of these types be taken.

(5.) The Committee recommend that the completion of the two sloops and the second-class cruiser fitting with Babcock and Wilcox boilers, and the sloop and first-class cruiser fitting with Niclausse boilers, be expedited, in order that the value of these types of boilers for naval purposes may be ascertained at the earliest possible date. This is especially important, as the Babcock and Wilcox boiler adopted in the ships under construction differs materially from the Babcock and Wilcox boiler as fitted in the *Sheldrake*.

(6.) The Committee recommend that boilers of the Dürr and of a modified Yarrow type be made and tested at the earliest possible date, under their supervision, with a view of aiding the selection of one or more types of water-tube boilers for use in His Majesty's ships. For this purpose the Committee suggest that two cruisers, not smaller than the "Medea" class, with vertical triple-expansion engines be placed at their disposal, and that they be empowered to order, at once, Dürr and Yarrow boilers to be fitted to them, and to order also the removal of their present boilers and the necessary modifications to their machinery, so that the performance of the types of boilers named may be definitely ascertained under ordinary working conditions from extended seagoing trials. The Committee suggest vessels not smaller than the "Medea" class, because the evidence before them shows that it has been difficult to draw from Torpedo Gunboat trials conclusions fully applicable to larger vessels.

(7.) With reference to paragraph (1), evidence has been given before the Committee to the effect that three most important requirements from the military point of view are:—

(*a*.) Rapidity of raising steam and of increasing the number of boilers at work.

(*b*.) Reduction to a minimum of danger to the ship from damage to boilers from shot or shell.

(*c*.) Possibility of removing damaged boilers and replacing them by new boilers in a very short time and without opening up the decks or removing fixtures of the hull.

These requirements are met by the water-tube boiler in a greater degree than by the cylindrical boiler, and are considered by the Committee of such importance as to outweigh the advantages of the latter type in economy of fuel and cost of up-keep.

(8.) The opinion expressed by the Committee in paragraph (2) has been formed after a personal examination of the boilers in a number of His Majesty's ships, including the *Diadem*, *Niobe*, *Europa*, *Hermes*, *Powerful*, *Furious*, and *Ariadne*; upon the statements of defects which have been placed before them; and the

evidence of the Chief Engineers of those vessels and other officers on the Engineering Staff of the Admiralty and Dockyards. This evidence is being printed, and will be forwarded when ready.

(9.) The Committee consider the following points in relation to the construction and working of the Belleville boiler to constitute practical objections of a serious nature:—

(*a.*) The circulation of water is defective and uncertain, because of the resistance offered by the great length of tube between the feed and steam collectors, the friction of the junction boxes, and the small holes in the nipples between the feed collector and the generator tubes, which also are liable to be obstructed, and may thus become a source of danger.

(*b.*) The necessity of an automatic feeding apparatus of a delicate and complicated kind.

(*c.*) The great excess of the pressure required in the feed pipes and pumps over the boiler pressure.

(*d.*) The considerable necessary excess of boiler pressure over the working pressure at the engines.

(*e.*) The water gauges not indicating with certainty the amount of water in the boiler. This has led to serious accidents.

(*f.*) The quantity of water which the boiler contains at different rates of combustion varying, although the same level may be shown on the water gauges.

(*g.*) The necessity of providing separators with automatic blow-out valves on the main steam pipes to provide for water thrown out of the boilers when speed is suddenly increased.

(*h.*) The constant trouble and loss of water resulting from the nickel sleeve joints connecting the elements to the feed collectors.

(*i.*) The liability of the upper generator tubes to fail by pitting or corrosion, and, in economiser boilers, the still greater liability of the economiser tubes to fail from the same cause:—

Further:—

(*k.*) The upkeep of the Belleville boiler has so far proved to be more costly than that of cylindrical boilers; in the opinion of the Committee this excess is likely to increase materially with the age of the boilers.

(*l.*) The additional evaporating plant required with Belleville boilers, and their greater coal consumption on ordinary service as compared with cylindrical boilers, has hitherto nullified to a great extent the saving of weight effected by their adoption, and, in considering the radius of action, it is doubtful whether any real advantage has been gained. The Committee are not prepared without further experience to say to what extent this may not apply to other types of water-tube boilers.

(10.) At the time the Belleville boiler was introduced into the Navy in the *Powerful* and *Terrible*, it was the only large tube type of water-tube boiler which had been tried at sea on a considerable scale, under ordinary working conditions. The Committee therefore consider that there was justification for then regarding it as the most suitable type of water-tube boiler for the Navy.

(11.) To obtain satisfactory results in the working of the Belleville boiler, in face of the defects named in paragraph (9), more than ordinary experience and skill are required on the part of the engine-room staff. It appears, however, from the evidence placed before the Committee, that the Engineer officers in charge of Belleville boilers have not been made acquainted with the best method of working the boilers, and that which experience has shown to be most effectual in preventing the pitting and corrosion of tubes.

(12.) In view of the rapid deterioration of economiser tubes in several vessels, the Committee have specially considered whether the extra power per ton of boiler at high rates of combustion, obtained by the use of economisers, has not been too dearly purchased. The evidence before them indicates that at the lower and more usual rates of combustion the *Powerful* type of boiler has given results as satisfactory as the economiser type. It is at the same time less complex, and free from the special risks of tube deterioration which have proved so serious in many cases, notably in the *Europa*. They therefore recommend, for ships under construction, that the non-economiser type should be reverted to where practicable, with the tubes raised higher above the firebars to increase the combustion space, and that where possible the steam collectors should be made larger, and more accessible internally.

(13.) The evidence before the Committee shows that a large proportion of the coal expended in the Navy is used for distilling and other auxiliary purposes, in harbour as well as at sea. For such purposes, the cylindrical boiler is, in the opinion of the Committee, more suitable and economical than any type of water-tube boiler. They recognise that there are objections to fitting cylindrical and water-tube boilers in combination, but they believe that those drawbacks would be more than compensated for by resulting advantages, observing that the cylindrical boilers could be used for supplying distilled water in case of failure or insufficiency of the evaporating plant. On these grounds, it is considered desirable that all the new vessels of large power should be provided with cylindrical boilers to do the auxiliary work.

(14.) The Committee have to state, for the information of their Lordships, that a series of comparative trials for determining economy in coal and water consumption were arranged in October 1900 for His Majesty's ships *Minerva* and *Hyacinth*. The trials of the former ship commenced on January 7th, as soon as she was ready, but were temporarily interrupted by recent events. The Committee are, however, now informed that the *Minerva* will not be again available until after March 2nd, and that the *Hyacinth* will not be ready to

commence her trials until the first week in April. It is proposed to include in these trials a full-speed run for both ships from Portsmouth to Gibraltar and back.

COMPTON DOMVILE, *Vice-Admiral and Chairman.*
JAS. BAIN.
JOHN INGLIS.
ALEX. B. W. KENNEDY.
JOHN LIST.
J. T. MILTON.

M. E. BROWNING, WM. H. WOOD, } *Joint Secretaries.*

I concur with the above Report, except as regards paragraph (3), and on the point dealt with in that paragraph my report is as follows :—

(1.) Although the Belleville boiler has certain undesirable features, I am satisfied, from considerable personal experience, and from the evidence of Engineer officers who have had charge of boilers of this type in commissioned ships, that it is a good steam generator, which will give satisfactory results when it is kept in good order and worked with the required care and skill.

I am also satisfied, from my inspection of the boilers of the Messageries Maritimes Company's S.S. *Laos*, after the vessel had been employed on regular mail service between Marseilles and Yokohama for more than three years without having been once laid up for repairs, that, with proper precaution, the excessive corrosive decay of the tubes which has occurred in some instances can be effectually guarded against.

(2.) Having in view the extent to which Belleville boilers have already been adopted for His Majesty's ships, and the fact that there are now three or four other types of water-tube boilers which promise at least equally good results, I am of opinion that, pending the issue of the final report of the Committee, Belleville boilers should not be included in future designs. At the same time, I see no necessity for delaying the progress of ships which have been designed for Belleville boilers in order to substitute another type of boiler. JOS. A. SMITH.

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Marine Boilers

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